Science beyond the classroom

Analysing the UK Science Education Community: The contribution of informal providers

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wellcome trust

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John Falk, College of Science, Oregon State University

Jonathan Osborne, Graduate School of Education, Stanford University

Lynn Dierking, College of Science, Oregon State University

Emily Dawson, independent UK consultant

Matthew Wenger, College of Science, Oregon State University

Billy Wong, independent UK consultant

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Executive summary

The aim of the work reported here has been to give an overview of the support that the informal sector provides for learning and engagement with science. In addressing this goal, we have taken the view that engagement with science and the learning of science occur both within and without schools. What is of interest is not who provides the experience or where it is provided but the nature and diversity of opportunities for science learning and engagement that are offered in contemporary UK society. Thus in approaching the work we have taken a systems perspective and looked at informal providers in particular, although we have also sought the views of those working in schools.

Methods and approach

The work reported here is based on: a set of 51 interviews which were conducted with informal and formal providers of science-based experiences across the UK; a survey of informal providers for which 196 responses were obtained; a reduced form of the same survey with schools, for which 23 responses were obtained; a systematic review of the academic literature; a further review of the existing 'grey' literature; and feedback from two symposia hosted by the Wellcome Trust.

In approaching the work, we have sought not to look at individual organisations and providers but to see science learning and engagement as a *system* of provision. To emphasise that perspective, we have drawn extensively on ideas in community ecology and compared the system of provision to that of a managed forest such as the New Forest. Doing this has enabled us to focus on what feeds the system, the extent to which it is self-sustaining or needs good management, the diversity of provision within the system, and potential imbalances that might need addressing.

Our view, based on existing research, is that there is already extensive evidence that individuals are engaged and develop much of their understanding and knowledge outside of the classroom. We begin by summarising key elements of this evidence. For instance, there is the well-known 'summer learning gap': research has shown that while students from low socioeconomic status (SES) backgrounds gain as much as high SES students over the course of the school year, they fall behind significantly during the summer, when they are not in school. Then there is the accumulating evidence of the enhanced educational attainment by children who attend pre-school where they are offered a diversity of unstructured, informal experiences. While school does matter in helping students develop formalised and general principles, it is the experiences outside the classroom that are essential to give meaning, relevance and context to the ideas that schools offer. The two are thus interdependent, and any society that provides one without the other has a less functionally effective educational system.

Major findings

Our first task was to try to identify the number of providers. Our initial hypothesis was to divide the community into 18 different sectors. However, our analysis of the survey suggests that there are at least 50 distinct niches within the system, while our analysis of the literature suggests that there are approximately 31. Thus the picture that emerges is of a diverse and rich community, although some of the niches are small and not readily recognised. Our analysis of which age groups they serve, when compared with the corresponding breakdown of the UK population (see figure 3), showed that young children under the age of five and adults are under-served. One consequence of this is a widely held perception that many of these institutions are 'for kids' – a perception which threatens their viability and opportunities to engage more adults with science. An analysis of goals and priorities, both for schools and for a range of informal providers, shows surprising unanimity where all sectors converged on just a couple of outcomes – 'make science enjoyable and interesting' and 'inspire a general interest in and engagement with science'. Whether all sectors are comparably effective at attaining such goals is unknown, but the common goal does point to sharing of a common enterprise.

Attempts to ascertain whom providers saw as important within their community tended to produce, not surprisingly, a 'me-first' response. However, all of them saw schools as being important. However, just as the trees in a forest are highly conspicuous, our view is that this finding is because of the existence of so many schools and because schools act as a gateway to the 5-to-19-year-old audience who are the focus of this study. Of particular note in the responses to the survey was that while most organisations reported collaborating extensively with one or more other members of the community, schools did so much less frequently (see figures 6 and 7). Moreover, whereas most members of the community reported collaborating with schools very frequently, schools reported collaborating with informal providers much less frequently. This finding leads us to ask whether schools are in some senses too dominant within the community, with an inward-looking nature that threatens their vitality as much as it does the other members of the community. Some organisations within the system emerged as both highly connected and highly reciprocal in their interactions. Our analysis revealed that science festivals, science and discovery centres and museums appear to be keystone sectors within the broader science education community.

Our work next looked at the knowledge that supports the system – effectively, what might be considered an important nutrient for feeding the system, enabling it to build on what has been done before and avoiding repetition of previous mistakes. Using a keyword search of major academic databases, over 4000 articles were found, which were reduced to a subset of 553 that were considered relevant to the field. An analysis of this literature would suggest that:

- There does exist a substantive body of empirical work and scholarship that addresses the field of learning science in informal contexts, but there are notable gaps.
- The field does have a theoretical base that draws on many of the ideas developed in research in formal education.
- There are a few researchers in the fields whose names arise with sufficient frequency to suggest that they have built a body of recognised scholarship.
- Research and scholarship in the field has been conducted within a very large number of disparate disciplines, making it difficult to locate and identify.

When we tested whether the 20 most highly cited elements of this literature were known to the field. At a symposium of key providers in the field, hosted by the Wellcome Trust in May

2012, we found that the modal (most common) value for how many individuals had read each publication was zero and the modal value for how many recognised but had not read each publication was two. The most read article had been read by less than 50 per cent of these key practitioners (11 people).

One response to this finding is that the field is much more reliant on the grey literature than other fields, but our analysis of a sample of this literature would lead us to question this view. Much of the literature lacks a research question, would appear to be over-reliant on surveys, fails to include the instruments used to gather the data (making it of little use to other providers), and is very difficult to find if the exact title is unknown. If this literature is considered valuable, why, we ask, has the community not established a central database and formal mechanisms for sharing it more widely? Another response is that the community is much more reliant on an apprenticeship model of learning akin to that used in medicine or teaching. However, if so, the community has failed to establish recognised means of acquiring such training. Moreover, other professions recognise the value of scholarship in helping them to identify new methods and theories that drive their thinking.

To answer these kinds of questions and others, the 51 interviews were transcribed and systematically analysed. This showed in more detail some of the values that members of the community operate with. For instance, informal providers are disposed to define themselves by how they are distinct from the formal community, while some in the formal community have a lack of respect for the work of the informal community. Such values are somewhat ironic when the survey would suggest that they both share common goals. The data also suggest that informal community members are overly reliant on ideas about learning and ideas about science that are somewhat simplistic. However, it must be said that the same point could probably be made about many working in the formal sector. Nevertheless, the findings point to a need for a better knowledge of salient literature and better systems of training. Another major feature of these data was the focus on engagement, making science 'fun' with the intent of teaching 'science by stealth'. Our concern here is that the literature would suggest that any enduring interest in a topic not only needs an initial stimulus but also needs to be sustained, and that the community has too much focus on the former at the expense of the latter. We also ask whether attempting to cloak or hide the difficulties of learning science is ultimately counterproductive and whether there is a lack of a vision of what can make science engaging.

These interviews also explored how the providers were addressing the needs of disadvantaged communities and engaging them with science. Few examples of good practice within the community were offered and there was less evidence that they are shared. Many providers saw schools as a conduit for addressing such concerns as they serve all communities. Give the enduring policy concern about the future supply of STEM professionals, it was surprising that more concern was not expressed about attracting and engaging more girls, women and other under-represented groups to science. From a systemic view, it is important that everyone in the community is provided for in some way – however, that does not require every provider to serve everyone. Ultimately, the responsibility for ensuring that the system addresses the needs of a diversity of audiences must be that of system managers rather than individual providers.

Recommendations

These arguments have led to the following recommendations:

Recommendation 1: There is need to build a stronger sense of a common identity among all providers of science education or educational experiences that support science learning and engagement. To this end, all those who contribute to any form of education, communication or engagement in science need a set of goals to help define their purpose and cultural contribution to society – essentially a manifesto for STEM. The Wellcome Trust should therefore establish a group of stakeholders and providers of STEM education to develop a set of goals and aims for STEM providers. These should be published as a short pamphlet and in a variety of formats.

Recommendation 2: Making the case for the value of the contribution made by informal providers of science education experiences requires better data on who works in the system, what are their goals and who they see as their audience. A central database needs to be established that registers such providers. The Wellcome Trust should establish such a database. Providers should be required to register their details as a condition of any funding and more broadly encouraged to do so by building a view that the data in this system are vital for defining the importance and contribution of the sector. As much of the data as possible on this database should be publicly accessible.

Recommendation 3: The Wellcome Trust should establish a small panel of major funders of out-of-school learning experiences whose responsibility would be to take a system overview. The aims and goals of this panel should be to:

a. commission reports and research on the functioning of different parts of the system

b. consider and review the strengths and weaknesses of the overall provision

c. take a strategic review, considering where the field needs to be strengthened, who or what is best capable of addressing that need, and how it could be funded

d. help define what are the priority aims and goals of the system as a whole.

While the focus of this panel would be on the informal sector, it would need to take a systemic view of the whole system that supports STEM learning. Hence, this panel should seek, as a priority, representation from the Department for Education and the Department for Business, Innovation and Skills so as to build a comprehensive system-wide view.

Recommendation 4: The science learning and engagement system needs support to build its knowledge base of which outcomes to measure and the ways in which they might be measured. Currently, the work on evaluating the system and building knowledge is undertaken by a large diversity of people, far too many of whom inhabit other communities. The system therefore needs to establish one or more centres for research, evaluation and training, with a particular focus on non-classroom-based STEM learning, whose function would be:

a. to help build our knowledge of how to measure the outcomes of participants' experience

b. to conduct reviews of relevant research and produce summaries for the field

c. to foster collaboration between the institutions and providers that occupy different niches so that the system can support the building of interest and the engaged science learner

d. to develop a range of training programmes for new and established members of the community who work in non-school-based provision of science learning and engagement.

To provide an incentive for providers to build and support the development of such centre(s), all bids for funding should be required to show how they have used, or intend to use, the expertise provided by these centre or alternatives.

Recommendation 5: The community needs to build on the knowledge that it is generating from its experience – that is, it needs to become a learning community. In addition, it needs to develop and keep up to date with contemporary thinking about the nature of science, practices in formal science education, and ideas about learning, motivation and engagement in the educational literature. A number of mechanisms are suggested which would encourage the community to become a learning community. These are:

a. working with other funders to establish a concordat that requires all bids for funding to show where they build on the literature and what people may have done before

b. requiring all bids for funding to show how and what they would contribute to the existing knowledge base and how such knowledge would be shared, at least within their own niche if not more widely

c. producing short focused summaries of relevant research in PDF format, which could be sponsored by the Wellcome Trust, ensuring they have status and authority within the community (a good model is the summaries of findings produced by the OECD PISA programme)

d. exploring other ways to encourage practitioners to publish and to use the existing knowledge base

e. exploring ways of offering certification and professional development for individuals working in this field, such as by establishing a Wellcome Trust fellowship for the informal sector that is competitive and enables individuals to be released to undertake a programme of professional learning.

Preface

International studies have recognised that children and adults pursue lifelong STEM interests and understandings, in and out of school, using a variety of community resources and networks[1]. Despite a growing body of evidence (described later in this report), too little is understood about these resources and networks, from either the provider or user perspective. In addition, we know next to nothing about how these resources and networks interact, connect, support or duplicate one another. We believe this is a major oversight. Real communities are composed of complex learning infrastructures of intersecting educational entities. Consequently, they are dynamic learning environments in which people engage, interact and make sense of the STEM they encounter in their daily lives.

In approaching our work, we have chosen to take a systems perspective to characterising the contribution made by informal providers. Why do we feel that this approach is useful? First, we believe that trying to understand the science education community in the UK as a system enables the field (providers, funders and, ultimately, users) to change its perspective, to view different parts of the science education community as contributing to a common goal. A systems perspective also allows us to focus at the institutional level on a wide range of organisations in the UK, from schools and museums to small companies delivering science shows. By examining the relationships between different parts of the science education community, we have attempted to understand how they interact and collaborate (or not). This approach also points to possible barriers to greater cooperation within and across educational sectors. If we can understand how formal and informal institutions/organisations work collaboratively in the service of STEM learning, this work will have helped to improve the quality of provision of STEM learning and engagement. Finally, analysing this community of institutions and practitioners as a complex system allows us to identify inadequacies of provision and key ways in which the system of informal provision might be made more effective.

This report is rooted in a belief that learning is both a process and a product, and while it is influenced by the personal, social and physical contexts in which it occurs, learning is learning regardless of context. As a consequence, learning is cumulative. And, rather than assessing the influence of any one experience, whether a school lesson or a visit to a museum, our view is that it is better to see learning as a product of experiences that happen across settings and over time. In this project, therefore, we have attempted to understand the settings, or what we characterise as the STEM learning community in which UK learners are immersed.

Inevitably, in any report of this nature there are omissions. When taking a systems perspective, what is omitted is the enormous passion, enthusiasm and professionalism of

1 Bell P et al. Learning Sciences in Informal Environments: People, Places and Pursuits. Washington: National Academies Press; 2009.

Stocklmayer SM et al. The roles of the formal and informal sectors in the provision of effective science education. Studies in Science Education 2010:46(1);1-44.

OECD. PISA in Focus 18: Are students more engaged when schools offer extracurricular activities? Paris: OECD; 2012.

many of the people who work in the system – individuals whose dedication sustains the system, often in the most difficult of circumstances on very limited resources. To some, what follows may seem critical. If so, it is done with the best of intentions – we seek only to suggest how a system, which has grown enormously in the diversity and extent of its provision, could with some more directed management and internal reflection, become an even more effective and important contributor to science education in the UK.

1. Introduction and context

Characterising the value of informal learning to science education in the UK and elsewhere is a challenging task. The view taken by the team conducting the research for this report was that this goal would not be achieved by merely identifying the major contributors to informal science education and attempting to document their individual efforts and outcomes. This is the primary approach taken by research to date. While this approach has provided valuable insights into the contribution that individual informal experiences make to STEM learning, it fails to recognise the contingent, lifelong and diverse experiences that support children's, young people's and adults' engagement with science, in both formal and informal environments. In short, our view is that it is not the one-off, individual experiences that matter as much as the totality provided by those engaged in STEM education – regardless of the context in which they happen. Therefore, in approaching this work we have sought to see if it is possible to construct a more holistic view of the system that supports STEM education, identifying the major agents/resources in that system engaged in the provision of both informal and formal STEM learning experiences and evaluating how well the system functions. Hence, our emphasis is on the whole system rather than its individual parts.

Understanding the science education community in the UK as a system is important because it enables a change of focus, to view different parts of the science education community and their contributions, and their relations to one another. This is particularly important if learning is seen as a set of cumulative experiences[2]. A young science learner, for instance, may experience a range of different science learning opportunities in a variety of contexts including those offered in school science classrooms, after-school science programmes delivered within a school environment, holiday programmes at local science centres, visits to botanic gardens and science festivals, Saturday mornings spent at a local library, and, of course, their home. From the perspective of the young learner of science, it is the context rather than the opportunity to learn science that changes. Yet these different contexts are typically studied in isolation, and little is known about the cumulative effect and the system that supports science learning and engagement.

Our hypothesis is that some of the current deficiencies in public STEM education, within both the informal and formal parts of the system, can be attributed to a failure to conceptualise STEM learning as a phenomenon that occurs over time within a complex community. So for example, many of the system's resources are either hidden or under-utilised by the public, particularly within poor, underserved neighbourhoods. Further, many of the agents that support STEM learning, both in and out of school, work in isolation, failing to see the opportunities for collaboration or exploiting opportunities afforded by other agents. This is not so much a fault of the individual providers who, quite naturally, are focused on ensuring the quality of what they provide and often exist in competition with each other – rather, it is a fault of a system that fails to sufficiently build and support collaborative links.

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2 Lemke J. Toward systemic educational change: Questions from a complex systems perspective. Planning Documents for a National Initiative on Complex Systems in K-16 Education. 1999. www.necsi.edu/events/cxedk16/cxedk16_3.html. Accessed September 20, 2012.

Falk J et al. Understanding STEM learning within a complex community: The Synergies Project. Proceedings of Korean Society of Elementary Science Education, (in press). Seoul National University Press: Seoul.

Thus, while providers offer valuable individual experiences, if they lack an awareness of their common shared goals, complementary approaches or a well-established professional base, they can fail to contribute to building a system of interconnected and interrelated STEM cultural experiences. In this report, we sought to test whether this hypothesis had any validity.

Considerable evidence exists that extensive learning does occur outside of formal institutions. Most notable, perhaps, is the 'summer learning gap' identified by several researchers[3]. These researchers have showed that while learning gains across the school academic year were comparable for low and high socioeconomic status (SES) students during the school year, approximately two-thirds of the difference in learning between these groups could be attributed to the learning experiences over the summer months.

Additional evidence of the importance of informal experience for learning also comes from the now considerable body of evidence which points to the positive advantage gained by attending pre-school[4] – which, while often formally structured, offers a diversity of informal experiences. Longitudinal studies, in some cases over 25 years, and in a range of countries, have consistently showed that children who attended pre-school attained higher educational levels and higher SES than those who had not.

Cole and Scribner's[5] review of the cognitive consequence of formal and informal education shows that students who have attended formal education develop abstract thought based on general, universal principles, while those who do not have any formal schooling are restricted in their knowledge to specific contexts and practices. However, whether the abstract principles learned in school become meaningful is highly dependent upon the range and diversity of experiences acquired outside of school. Students who lack such experiences may know the words and can repeat them in examinations; however, without any sense of what they might refer to, they become empty verbal constructs. In short, students' experiences outside of school help them to make sense of the abstract concepts they meet in school.

Another form of learning is observational learning. Here an adult will demonstrate a practice, and the learner will observe and then attempt to replicate the practice while the adult provides formative feedback on their performance. This is evident in Rogoff's studies of how Mayan children learned weaving through participation[6]. Such learning has the advantage that it often occurs in highly personal and meaningful contexts. Formal schooling can then

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3 Alexander KL et al. Lasting consequences of the summer learning gap. American Sociological Review 2007;72:167-80.

Downey DB et al. Are schools the great equalizer? Cognitive inequality during the summer months and the school year. American Sociological Review 2004;69(5):613-35.

4 Melhuish EC. Preschool matters. Science 2011;333:299-300.

Magnuson K, Waldfogel J. The Role of Early Childhood Education in Changing Income-Related Gaps in Achievement. Presented at Conference on Income, Inequality and Educational Success, May 2012: Stanford, CA.

5 Cole M, Scribner S. Cognitive Consequences of Formal and Informal Education. Science 1973;182(4112):553-9.

6 Rogoff B et al. Firsthand Learning Through Intent Participation. Annu Rev Psychol 2003;54:175-203.

draw on these experiences, giving meaning to the many abstractions and challenging concepts that the student encounters in school science. Sometimes referred to as 'funds of knowledge', this interaction between formally and informally acquired understandings has been shown to be quite powerful in supporting learning, particularly amongst ethnic minorities in the USA[7].

Evidence to support this view comes from an analysis of the PISA 2006 student questionnaire data, which cover the activities that students engaged in outside of school. This found that science-related extracurricular activities were related to better student performance, a stronger belief by students in their abilities to undertake science-related tasks, and greater enjoyment in learning science[8]. This relationship was found to exist for 22 of the 31 OECD countries, and for some countries such as Germany it accounted for 15 per cent of the variance in student performance. In addition, students in schools that offer more science-related extracurricular activities tended not only to perform better in science, but also to report more positive attitudes towards science. Such students believed in their own ability to handle science-related tasks effectively (known as self-efficacy) and enjoyed learning science. In the UK, however, a positive effect only existed for students from a higher SES background. The lack of any broader effect in the UK implies that that there is a large imbalance between the experiences that UK society affords children from higher and lower SES backgrounds. If this is true, it points toward the urgency of redressing the imbalance of provision of informal learning experiences in the UK.

Further evidence of the value of informal contexts for learning can be found in a recent study by Falk and Needham[9]. These researchers studied the relative contributions of five potential sources of adults' understanding of science – schooling, childhood informal/free-choice experiences, adult informal/free-choice experiences, workplace learning and 'privilege' (the impacts of race/ethnicity, family income and gender). All five sources were found to have contributed significantly to the adults' science knowledge. Schooling and childhood informal experiences each accounted for 17 per cent of the total variance, workplace experiences accounted for 20 per cent of the variance, privilege accounted for 23 per cent and adult informal experiences accounted for 39 per cent. Not surprisingly, there were interactions between all variables, suggesting the importance of synergistic impacts. However, a key finding was that engagement in informal activities during both childhood and adulthood strongly contributes to an individual's understanding of science.

As we shall show, despite abundant evidence about the value of learning experiences outside of school, this evidence base is not well known or used by formal or informal practitioners. Its importance is at least understood by the Headmaster of Eton, who, when asked to account for the success of his school, stated that the school recognised that "young

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7 Moll LC et al. Funds of knowledge for teaching: using a qualitative approach to connect homes and classrooms. Theory into Practice 2002;31:132-41.

8 OECD. PISA in Focus 18: Are students more engaged when schools offer extracurricular activities? Paris: OECD; 2012.

9 Falk JH, Needham M. Factors contributing to adult knowledge of science and technology. Journal of Research in Science Teaching 2012 (in press).

people teach each other more than adults think they teach them, and, secondly, that at least as much learning goes on outside the classroom as within it"[10].

Some might seek evidence in the form of randomised controlled trials. However, these are very difficult to run in the complex contexts where informal learning occurs. Even then, one study that did use such a design found that groups that engaged with inquiry-based games at the Exploratorium significantly outperformed control groups in the quality and duration of several inquiry skills[11]. Finally, a belief in the value of such a method fails to recognise that learning is rarely something that is a product of a single experience. Rather, learning is the product of an accumulation of both formal and informal experiences[12] and repeated practice,[13] which relies extensively on engagement in a set of key discursive practices[14].

On average, only 18.5 per cent of a Year 1–11 student's waking hours are spent in school, as in figure 1, showing the amount of time typically spent in formal education in the USA[15].

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10 Eyres H. Bold Etonians. Financial Times, Life and Arts Section, 23 May 2008: 1.

11 Gutwill J, Allen S. Deepening students' scientific inquiry skills during a science museum field trip. Journal of the Learning Sciences 2012;21:130-81.

12 Cole M, Scribner S. Cognitive consequences of formal and informal education. Science 1973;182(4112):553-9.

Falk JH, Needham M. Factors contributing to adult knowledge of science and technology. Journal of Research in Science Teaching 2012 (in press).

Moll LC et al. Funds of knowledge for teaching: using a qualitative approach to connect homes and classrooms. Theory into Practice 2002;31:132-41.

13 Lemke J. Toward systemic educational change: Questions from a complex systems perspective. Planning Documents for a National Initiative on Complex Systems in K-16 Education. 1999. www.necsi.edu/events/cxedk16/cxedk16_3.html. Accessed September 20, 2012.

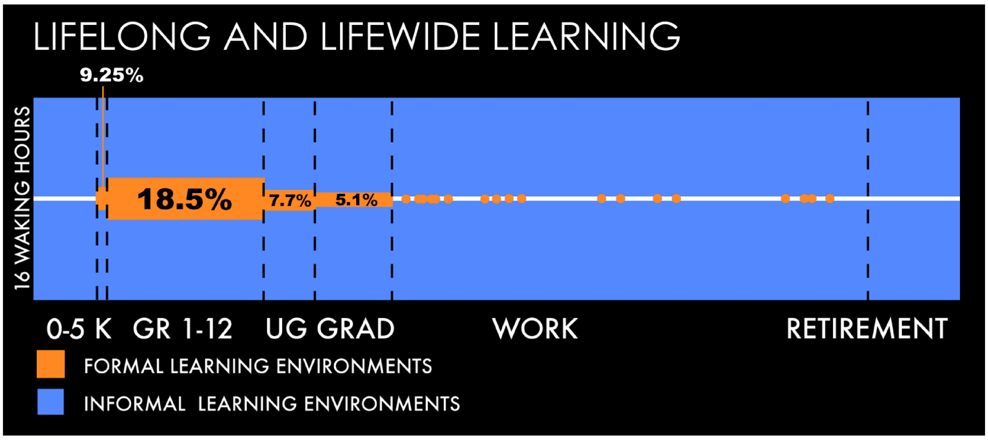
Falk JL et al. Understanding STEM learning within a complex community: The Synergies Project. Proceedings of Korean Society of Elementary Science Education (in press). Seoul National University Press: Seoul.

Ericsson KA et al. The role of deliberate practice in the acquisition of expert performance. Psychological Review 1993;100(3):363.

14 Ohlsson S. Learning to do and learning to understand? A lesson and a challenge for cognitive modelling. In: Reimann P, Spada H (eds). Learning in Humans and Machines. Oxford: Elsevier; 1996. pp. 37-62.

15 Bell P et al. (eds). Learning Science in Informal Environments. Washington, DC: National Academies Press; 2009.

Figure 1: Proportion of time spent in formal education for a typical US person



The other 82 per cent provides a host of opportunities such as TV, films, newspapers and magazines, the internet, science centres, museums, sports and hobbies where individuals will engage with and learn science of some kind. While the role of formal education may be critical in determining an individual's life chances and their future opportunities, in today's cultural environment, informal environments are increasingly a source of information and learning[16] that supplement and support formal learning.

Making use of the informal environment, however, is motivated and driven by individual interest. Likewise, studies of students' engagement with science show consistently that it is interest that motivates student learning[17]. An important model for how such interest develops comes from the work of Hidi and Renniger,[18] suggesting that any interest passes through four stages. Stage 1 is where interest is triggered by a chance event. This is followed by stage 2, where situational interest is sustained and, typically, is supported externally by learning activities that provide meaningful and personally involving activities. At stage 3, the individual has an emergent developing interest and has become predisposed to seek repeated engagement with the activity. Finally, stage 4, mature well-developed interest, is characterised by an enduring disposition to re-engage with the topic or activity. A learner with this kind of interest will persevere or address a question even in the face of frustration. Such learners are said to be mastery learners and are developing the kinds of skills necessary for lifelong learning and, undoubtedly, the kind of motivation necessary to master higher-level STEM concepts. Thus, arguably one of the major contributions of the informal part of the science education community is its capacity to trigger, sustain and build such interests.

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16 Falk J, Dierking L. The 95 percent solution: school is not where most of Americans learn most of their science. American Scientist 2010;98:486-93.

17 Ormerod MB, Duckworth D. Pupils' Attitudes to Science. Slough: NFER; 1975.

Tai RH et al. Planning early for careers in science. Science 2006;312:1143-5.

Royal Society. Taking A Leading Role. London: The Royal Society; 2006.

Bøe MV et al. Participation in science and technology: young people and achievement-related choices in late-modern societies. Studies in Science Education 2011;47(1):37-72.

18 Hidi S, Renninger KA. The Four-Phase Model of Interest Development. Educational Psychologist 2006;41(2):111-27.

The importance of this role is starkly highlighted by data from PISA and TIMMS which show that there is a negative correlation between a country's average level of student interest in school science and its average level of student attainment[19]. However, when the top performers on PISA within countries are examined, the OECD found that:[20]

> …top performers in science are engaged science learners: they report that they enjoy learning science, that they want to learn more, that their science lessons are fun and that they are motivated to do well in science…Over 80% of top performers report that they enjoy acquiring new knowledge in science, are interested in learning about science and generally have fun when learning science whereas only 50% of lowest performers did so.

Students' accounts of what initiated the interest that has sustained their engagement with science point to the family environment, contingent informal experiences[21] or the perceived extrinsic value of science qualifications[22]. Thus the role of the informal community in contributing to the supply of future STEM professionals and, more generally, to establishing the significance and value of STEM in our culture should not be underestimated even if it cannot readily be measured.

Some sense of the cultural value provided by the community who provide out-of-school learning experiences can be seen in the data provided by the Public Attitudes to Science Survey[23]. Figure 2 summarises the main highlights of how much use the general public makes of such experiences. It shows what percentage of the public visited one of these facilities or events at least once in 2010. More extensive summaries can be found in section 3.1.1 of the GHK report.

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19 Osborne JF, Dillon J. Science Education in Europe: Critical Reflections. London: Nuffield Foundation; 2008.

Avvisati F, Vincent-Lancrin SP. Effective Teaching for Improving Students' Motivation, Curiosity, and Self-Confidence in Science: A Comparative Approach. Paris: Centre for Educational Research and Innovation, OECD; in press.

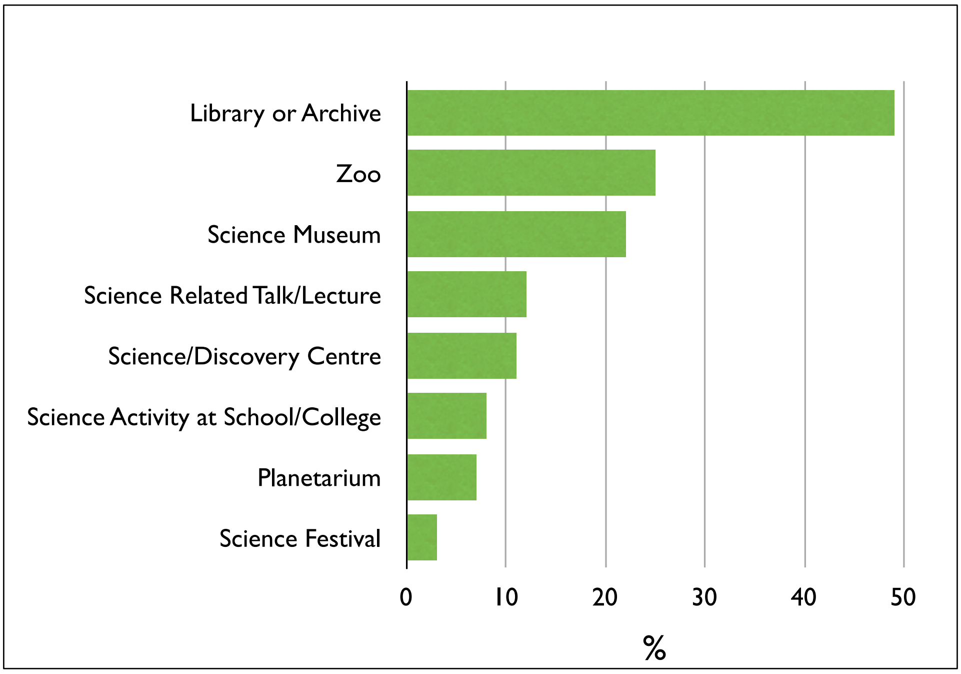
20 OECD. Top of the Class. Paris: OECD; 2009.

21 Bøe MV. Science choices in Norwegian upper secondary school: What matters? Science Education 2011;96(1):1-20.

22 Lyons T, Quinn F. Choosing Science: Understanding the declines in senior high school enrolments. New South Wales, Australia: SiMERR National Centre: University of New England; 2009.

23 Ipsos MORI Social Research Insititute. Public Attitudes to Science 2011: A Survey. London: Department for Business and Skills: 2011.

Figure 2: Percentage of the population participating in science-related leisure activities in the UK in 2010 [25]



Given that the current UK population is approximately 62.5 million, figure 2 shows that large numbers of people make use of informal learning experiences. Of note is that overall, two-thirds of those in social categories AB were found to have engaged in a science-related activity during the course of the year compared to just one-third in categories DE. In addition, 54 per cent of people indicated that a major source of information about science was the television and 32 per cent the newspapers.

1.1 Data sources

In order to build a deeper understanding of the system that supports the learning of science outside of formal education, four sources of data were used:

- a systematic review of the academic literature to identify the main findings and theoretical perspectives in the literature;
- 51 interviews conducted with a purposively selected group of senior and middle managers drawn from 18 distinct 'sectors' of providers of educational experiences in science[24];
- a set of data collected from a survey distributed widely across the UK, from which 196 responses from a wide range of primarily informal education providers were obtained, plus a supplemental abbreviated version of the survey completed by 23 formal educators;

24 Although 55 interviews were conducted by GHK, four of these were with funders or academics who were not providers of non-school learning opportunities. Hence these were not transcribed.

- two symposia conducted in London at the Wellcome Trust to explore the nature of informal education providers and the views of the attendees.

Further details about the data sources are provided in the Methodological Annex.

In what follows, we present our analysis of the data and discuss its implications. The goal of this work has been to understand the UK science education community as a system and to understand how, as a system, it might more readily fulfil its potential. A particular focus of our work has been to identify those elements that stimulate interest in STEM and the structures that might sustain lifelong, life-wide and life-deep STEM learning.

Emerging from our analysis are two major themes. These are:

- the need to drive the field that supports education and learning in science towards conceptualising itself as a complex, interconnected system in which each provider of informal learning experiences is a part

- the need to support the field in becoming more reflective and evidence-based in its practice, helping it to acquire more sophisticated models of science, the value of science, how science is learned and what makes science interesting and engaging.

2. Taking a systems/ecological approach

We believe that it is important to view the UK science education community as a complex, ecological system. To support this 'ecological' view we propose using ecological sciences and ecological frameworks as a metaphor for this community.

We begin by clarifying our frame of reference. In our initial proposal for this work, we used the analogy of an ecosystem to describe UK science education. Further reflection about this analogy led to the realisation that, from an ecologists' point of view, while UK science education does exist within an ecosystem, that ecosystem includes a wealth of large-scale factors, including national politics and the economy, that clearly lie beyond the scope of this initial investigation. Thus, the more appropriate framework for our analysis was to think about UK science education from a community ecology framework. Community ecology is a well-established sub-discipline of ecology which studies the interactions, patterns and relationships between species in communities on many spatial and temporal scales, including the distribution, structure, abundance, equitability and interactions between coexisting assemblages of organisms[25].

2.1 The community ecology of the whole UK science education system

The first step in the analysis of a community is to develop a rough understanding of who lives in the community; in particular, it is essential to account for the types of organisms that live within the ecological community and the general niches they occupy (we use the concept of ecological niches in this report to describe how an organism responds to the distribution of resources and competitors within the community and how organisms in turn alter those same factors). Given the scale of our investigation – which included the entire UK science education community, both formal and informal – and given the limitations in scope and intensity that were imposed by time and funding, we have taken a very conceptual and broad-brush approach to the problem. Rather than focusing on each individual organisation within the UK science education community, which would in this analogy be comparable to investigating each type of organism living within a community, we chose to think initially in terms of large functional groupings of organisations. For example, we began by looking at major groupings such as science centres, broadcasters and schools. By analogy, ecologically this would be like considering major functional categories like 'large mammalian grazers', which in a UK forest might include organisms like deer and possibly also domesticated species like horses and cattle. Appropriate to an ecological analysis, we did not focus on the taxonomic relationships of these groupings, i.e., whether they are closely related or not (in our example, deer and horses are not), but rather on their ecological functions – that is, what role they play in the system. We built up our understanding of these groupings by asking members of the science education community to reflect on how they perceive their grouping or sector to function. We appreciated from the beginning that these groupings might provide only a coarse-grained understanding of the dynamics of the community, given that each of the sectors we delineated is actually made up of individual

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25 Morin PJ. Community Ecology. New York: Wiley-Blackwell Press; 2009.

organisations, which in turn can be quite diverse. Moreover, within each sector there are both large and small organisations, some of which may be specialists, with very narrow, specialised niches, and others who function as generalists, serving a wide range of users in a diversity of ways.

In our initial conceptualisation, we designated 18 sectors that we and other stakeholders viewed as contributors to UK science learning. The task of gathering survey data from all 18 of these sectors was challenging. Although we had excellent responses from three-quarters of the sample, sectors with fewer than five responses included electronic media producers, parks/nature/field centres, and theatre groups. Additionally, we had no survey participants from three sectors: community/hobby groups/sports clubs, libraries and publishers of printed materials. More troubling than response rates, though, was the discovery upon initial review of the survey data that, for several of these initial 18 groupings, the distribution of responses to certain questions about their key function lacked any central tendency. In other words, respondents within many of the designated ‘sectors’ actually represented a heterogeneous grouping of organisations and not an actual sector[26]. In fact, even such apparently obvious groupings as the school sector emerged as heterogeneous[27]. Although our initial grouping of science education providers was based upon an informed hunch about the nature of science education in the UK and informed by previous work in the USA,[28] as well as the way the community is often delineated, this initial classification of sectors did not totally hold up to scrutiny. Although the broad generalisations we will make below about the UK science education community were not affected by these distortions in the data, specific elements were.

The first thing we sought to investigate was how, collectively and individually, these different sectors function, for example who do they serve? Not every sector is likely to be capable of meeting the needs of every age group, but we would hope that the community collectively would be serving the needs of all citizens. Figure 3 shows the proportionate sizes of different age cohorts within the total UK population and compares these with the data obtained from the survey for the number of providers who said they served the same age group. Thus it illustrates how, collectively, the science education sectors in this study prioritised different audiences relative to the sizes of hose audiences[29].

What clearly emerges in figure 3 is that, although every age group is a priority of someone within the science education community, these audiences are not being equally served given

26 The incomplete response rate and the problems associated with who was placed in some of the ‘sector’ categories undoubtedly influenced results. Readers should keep this potential bias in mind when reviewing findings and conclusions.

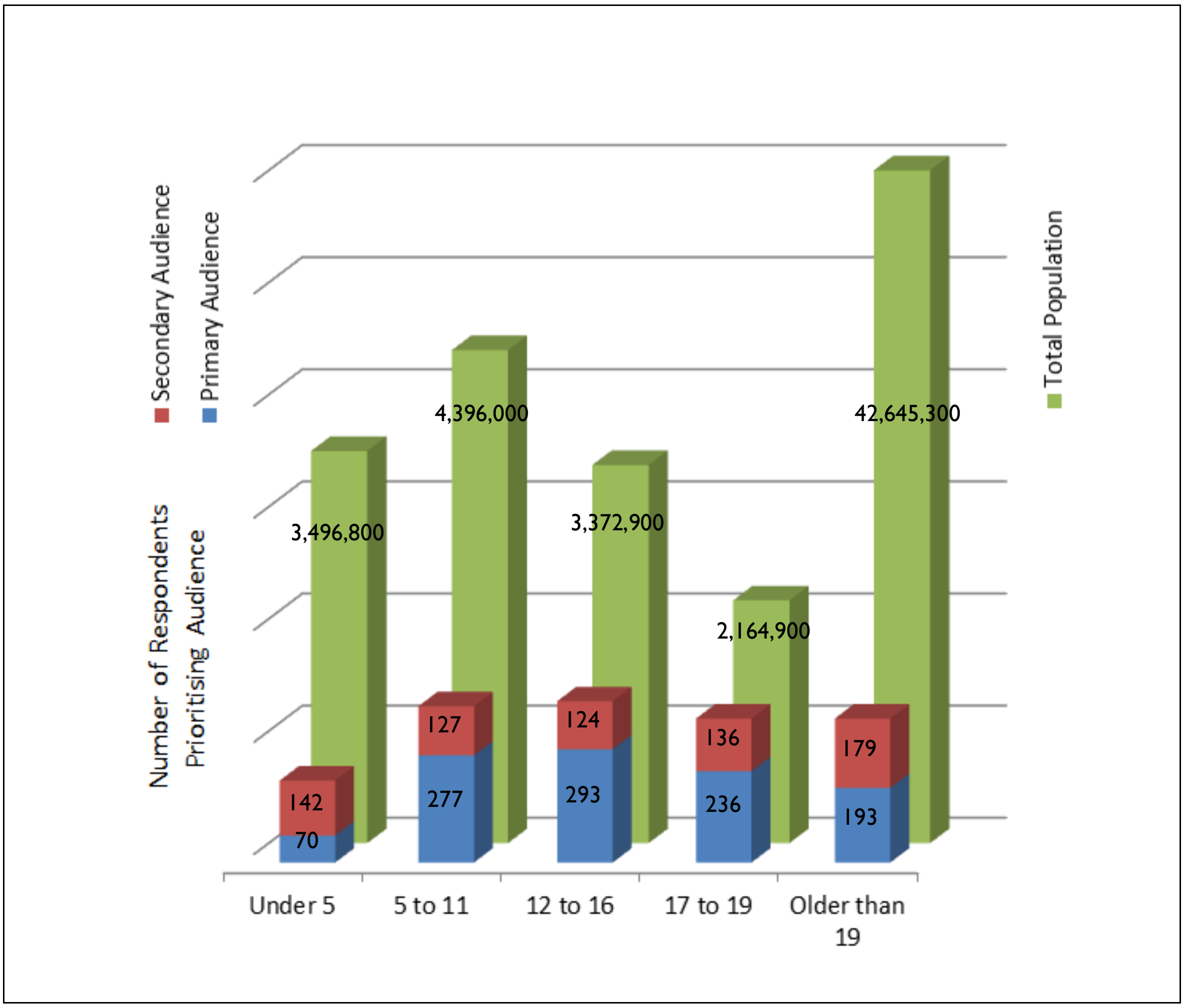
27 We conducted a preliminary analysis of the survey data using hierarchical cluster analysis to see if we could determine how many actual sectors there were. The resulting dendrogram of relationships suggested something on the order of 50 different groupings of science education providers. However, the quality of the data limited our ability to push this analysis further at this time.

28 Bell P et al. (eds). Learning Science in Informal Environments. Washington, DC: National Academies Press; 2009.

29 Family groups were an important audience for many groups in the survey and this audience obviously includes both adults and children, particularly younger children. However, these data were excluded from figure 3 because of a lack of ability to accurately apportion the data.

their size. In other words, although it is generally assumed that primary-school-aged audiences are being adequately served by the system, this analysis might suggest otherwise. Interesting too is that the demographic of 17-to-19-year-olds that many claim to be ‘hard to reach’ is comparatively well-served. In contrast, children under the age of five are underserved.

Figure 3: Comparing the age distribution of the UK population with the distribution of audiences said to be served by survey respondents*



* Note: The final bar for the adult population is not drawn to scale in order to better show the relative distribution. This means that the disparity between the size of the audience and the number of providers is much larger than might be implied by the graphic.

Also suggested by these results is that, relative to their numbers in the population, adults are being significantly underserved by the UK science education community. Although the focus of this survey was children, this particular survey question specifically asked respondents to include adults in their responses. Although it is possible – in fact, likely – that there were science education providers excluded from this survey who do exclusively focus on adults, the groups who were included are generally considered the major providers of science learning experiences in the UK.

Missing from the data in figure 3 are 22 providers who said that their primary audience was family groups. These were excluded from figure 3 for lack of any way of accurately apportioning the data. We do not feel, however, that this significantly alters the basic issue raised by figure 3. Data from the USA, for example, show that the majority of family visits to informal venues disproportionately include children between the ages of 5 and12. Other data, also from the USA, show that a majority of the adults on these family visits focus almost exclusively on their children's experience rather than their own science learning. Thus, even if we had included this family visit data in figure 3, it would not have appreciably changed our argument that the distribution of science education provision in the UK appears to favour school-aged children at the expense of those younger and older.

It could also be argued that while there are a very few providers who specifically target adult audiences or children under the age of 5, these may have substantial capacity. In the case of children under the age of 5, there is very little evidence that there are institutions that do target this audience. For instance, in the UK, there is only one institution we know of which specifically targets this audience. In the case of adult audiences, our approach did not distinguish the size of the audience that the institutions thought they served. Nevertheless, our knowledge of the system and providers would suggest that although there are a few centres that provide intensive experiences for adults (e.g. the Darwin Centre, Café Scientifique and Wellcome Collection), none of these have very large capacity. All of this evidence leads us to believe that there is an overemphasis on the 5–16 audience, resulting in a lack of capacity for very young children and adults. A further complication of this school-aged focus is the potential for fostering the perception among adults that engaging in science is an activity for kids, not for them.

Although our survey data did not permit a comparable analysis as a function of geography or socioeconomic status (SES), our hypothesis is that a similar reality exists within these dimensions as well: first, that the public within metropolitan areas are receiving proportionately more attention than the public in more rural communities (though such measures as these do not account for quality); secondly, that individuals from higher SES audiences are being more adequately served than are lower SES audiences, despite the efforts by many members of the science education community to specifically target disadvantaged communities, as discussed in the GHK Report.

As to their primary goals, one of the survey questions asked all institutions to rank their goals from a list. Interestingly, all respondents, including schools, converged on just a couple of outcomes – 'make science enjoyable and interesting' and 'inspire a general interest in and engagement with science'. The least supported outcomes for all sectors, including schools, were 'prepare participants for future STEM education or careers' and 'encourage further learning in non-science subjects'. This convergence in outcomes across all sectors is an important finding: it could be used to encourage greater collaboration within and between sectors across the community.

The next level of analysis was to try to look more closely at relationships within and between groups – how do the groups of organisations interact within the community as a whole, what interrelationships exist, are relationships between sectors symmetrical and mutually beneficial (i.e. symbiotic) or more one-sided (i.e. commensal or parasitic)? To make this analysis more concrete, particularly for readers who are not ecologists, it is useful to think of the UK science education community as analogous to a forest community such as that which exists within the New Forest National Park in the south of England. This particular example has the added benefit of being a managed system. Although no system, be it a forest or a social network, can ever be said to be totally 'managed', the New Forest, much like the science education community in the UK, has variously benefited and suffered over the years from human interventions which respectively have attempted to conserve or exploit it.

2.2 Conceptualising UK science education in terms of a managed forest

Forests are complex, highly evolved communities involving large numbers of individual species interacting in multiple interconnected webs. Although we can visualise and describe an ecological community as a discrete entity it is important to appreciate that all communities are parts of a larger system – the ecosystem in which they are embedded – as well as interconnected with other nearby communities. So, using our forest community example we can appreciate that the forest, though a discrete entity, is part of a larger ecosystem. In the case of the New Forest, it is situated within the European temperate deciduous biome, which is made up of myriad sub-communities both directly, e.g. through the interlacing of forest, heath, meadow, bog, agricultural and river communities, and indirectly, by the active and passive transport of air, water and organisms across and within the larger European system of which it is part. Over the centuries people too have played a huge role in the New Forest's ecology, often as non-residents, harvesting various resources such as wood, or using the forest as a place to graze livestock, feed swine or hunt deer for pleasure. Thus the ecology of the forest is determined both by organisms resident within the system as well as by organisms that live much of their lives outside the forest's boundaries. Analogously, the UK science education system is embedded within the larger political and social system of the UK and Europe and interfaces with other communities such as the arts and cultural education community and the leisure and tourism community, as well as having occasional involvement from other professionals such as university researchers or software developers.

In examining the structures and relationships of the various sectors within the community, one important question is which of the sectors seem critical to the functioning of the system. Ecological dogma would suggest that all members of a community are interconnected and thus at some level play a role in the structure and functioning of the system. That said, there are clearly some groups that are more influential than others, whether defined in terms of energy capture, availability of carbon resources, maintaining ecological balance, or some other specific community 'goal'[30]. These 'keystone functional groups' may not be the most numerous or conspicuous members of the community; major predators such as wolves and mountain lions have been shown to play a role disproportionate to their numbers in maintaining healthy forest communities in North America by controlling the numbers of large herbivores and preventing deforestation[31]. And, in the case of the New Forest, what are described as 'veteran trees' are considered a keystone group[32].

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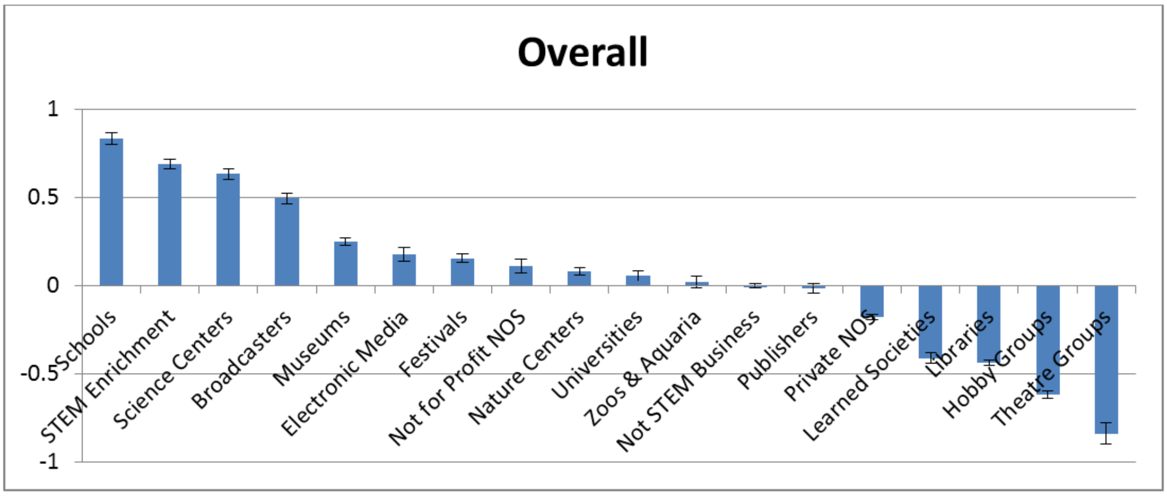
30 Paine RT. A conversation on refining the concept of Keystone Species. Conservation Biology 1995;9(4):962-4.

31 Smith DW et al. Yellowstone after Wolves. Bioscience 2003;53(4):330-40.
Ripple WJ, Beschta RL. Wolves, elk, willows, and trophic cascades in the upper Gallatin range of Southwestern Montana, USA. Forest Ecology and Management 2004;200:161-81.

32 The terms 'veteran tree' and 'ancient tree' are not interchangeable. The term 'ancient' refers specifically to the age of a tree and is used to describe the life-stage of the tree as 'beyond full maturity'. The term 'veteran tree' includes this important ancient category and also takes in other tree specimens which, while not truly ancient

What, then, appear to be the keystone functional groups within the UK science education community? In other words, who are the analogues of veteran trees in this system? Survey participants were asked to rate, from their perspective, each of the 18 sectors on its relative importance to science education overall in the UK. Figure 4 summarises the normalised[33] responses from the 219 respondents. They rated schools to be the most influential for science learning, with organisations that provide STEM engagement and enhancement activities, science and discovery centres, and broadcast media also viewed as major contributors. Theatre groups, community groups, hobby clubs, sports clubs, libraries and learned societies were rated the least important.

Figure 4: Normalised overall survey rankings to the question 'Who's most important…'



So what does this mean? Are schools, organisations that provide STEM engagement and enhancement activities, science and discovery centres, and broadcast media really the most important constituents of the UK science education community – the keystone groups – and are hobby clubs and theatre groups minimally useful? Or do these rankings merely reflect who within the community are the most conspicuous (and who were best represented among survey respondents)? Our view is that the latter is a more reliable interpretation. Evidence that the responses summarised in figure 4 do not actually provide a completely accurate picture of ecological importance comes from a more fine-grained analysis. Respondents from each sector tended to answer from a largely egocentric viewpoint, rather than a systemic one. By way of example, figure 5 shows the responses to the question of 'who's important?' from three sectors – science and discovery centres, universities and

in years, have some of the same characteristics. For example, in addition to their notable girth, veteran trees also possess an abundance of dead or decaying wood, and a range of cavities, hollows and rot-holes, which are colonised by fungi and invertebrates, bats and birds.

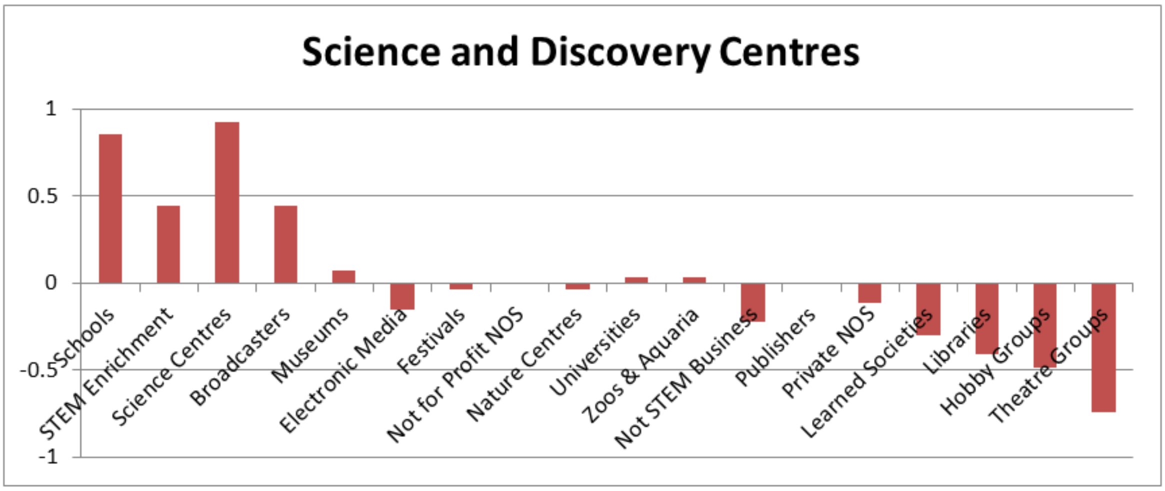
33 By normalised, we mean that a mean response from each of the 18 sectors was utilised – responses varied from +9 (total agreement by all respondents that this sector was one of the three most influential) to -9 (total agreement by all respondents that this sector was one of the three least influential). Error bars are included to make clear if, for example a mean score of 0 resulted from half of respondents scoring a sector high and half scoring it low; this could have been the case particularly in the middle of the range. As the error bars show, this did not happen.

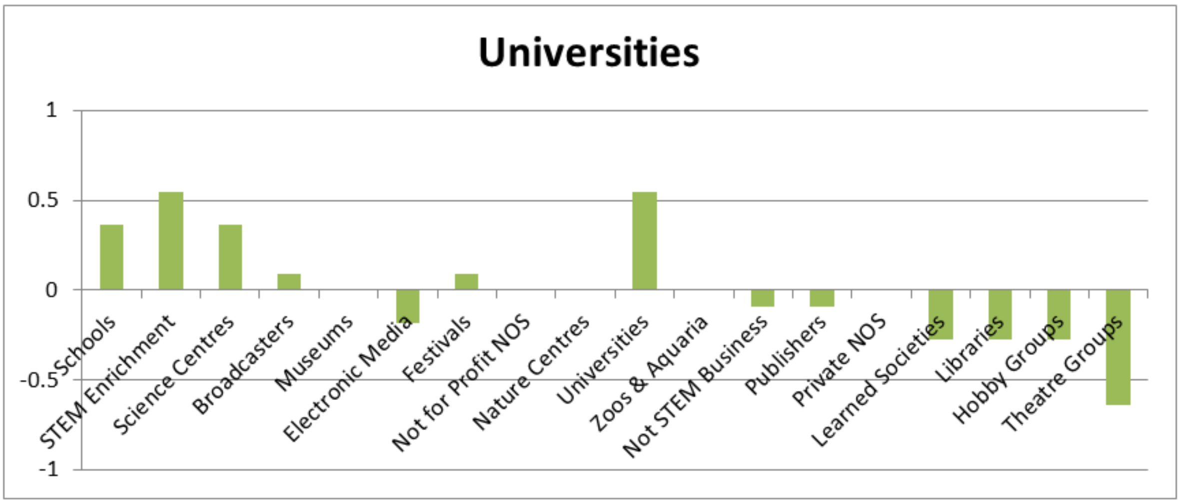
learned societies – one representative group selected from each of the top, middle and bottom thirds of the ratings in figure 4.

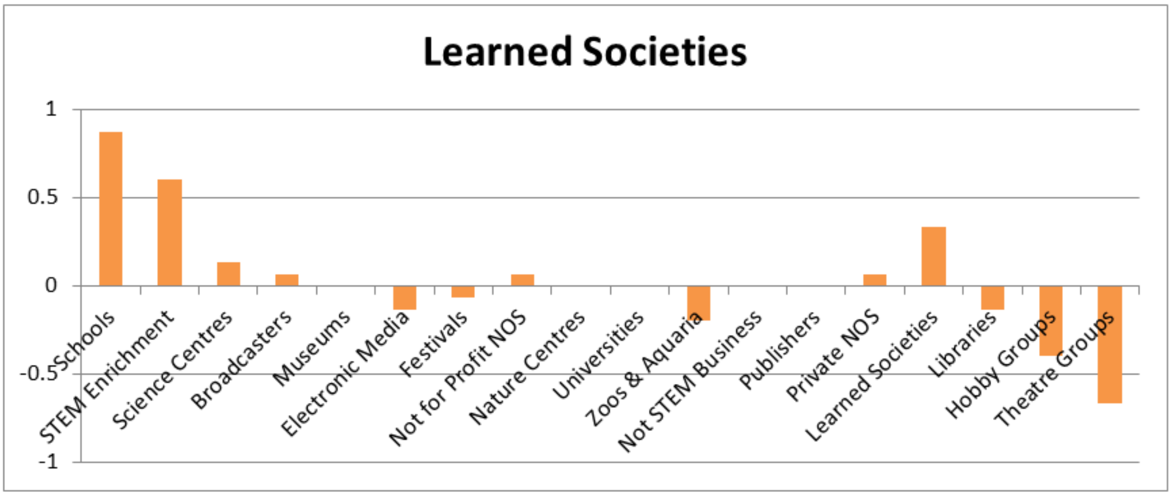
Although there are some similarities within each of these three-sector-specific responses to those in figure 4, there are also stark differences. In particular, each of the three sectors featured below answered the question of 'who's important?' in terms that reflected their own particular perspective of the world, specifically indicating that their own sector was highly important.

This is where the forest analogy provides some clarity on the question of 'who's important?' It would be like asking all the various species of deer living in the New Forest: who's important in the forest? Clearly they would think that the various species of deer are important; they would also likely list other members of the forest conspicuous and important to them, perhaps their main source of food such as a particular kind of nut, acorn or berry; no doubt they would mention their main predators, people; and certainly the deer would mention the trees of the forest as important since that is the habitat in which they have to operate.

Figure 5a-c: Normalised survey rankings to the question 'Who's most important…' for different sectors







However, the woodpeckers in the community would have responded to the question of who is important very differently; again noting what's important to them such as trees and competing woodpeckers, but probably not mentioning deer and maybe not even people. Thus, figure 5 clearly shows this 'me-first' view that science education organisations in the UK currently possess. One thing that does seem to emerge from this question, though, is a consensus that schools are important, as are other large and conspicuous inhabitants of the science education community such as major science and discovery centres, broadcasters and whatever respondents assumed was meant by the catch-all category 'organisations that provide STEM engagement and enhancement activities' (shown as 'STEM enrichment' in figure 5).

Using this analogy of the New Forest, far and away the most conspicuous inhabitants are the trees, perhaps followed by species of common, large herbivores like deer, and then perhaps other common and conspicuous vertebrates like woodpeckers. However, these common, large and conspicuous organisms are, from an ecological perspective, not necessarily the most important. As previously indicated, the keystone organisms in New Forest are not the trees *per se*, but specific kinds of tree; in this case trees that are important by virtue of their age and structure rather than their species. Moreover, although totally invisible to us humans, as in most ecological communities, small and inconspicuous members of a community can also have a disproportionate impact[34]. For example, it was only relatively recently discovered that underlying all temperate forest systems, including, it is assumed, the New Forest, are a range of critical, below-ground fungi called mycorrhizae[35,36]. We would suggest that schools play a role within the UK science education community analogous to trees within the forest. They clearly are important and conspicuous, but they may or may not function as keystone organisms. What's less clear is what might be

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34 Levins SA. Ecosystems and the biosphere as complex adaptive systems. Ecosystems 1998;1:431-6.

35 Brundrett M. Mycorrhizas in natural ecosystems. Advances in Ecological Research 1991;21:171-313.

36 Forest mycorrhizae are a symbiotic association between various fungi species and the roots of the forest trees. It has been estimated that the biomass of the below-ground mycorrhizae equals or exceeds that of the above-ground trees. Beyond just size, mycorrhizae turn out to be critical to the health of forest. While the trees make carbohydrates available to the fungi, the fungi make it easier for the trees to take up water and to capture and utilise key nutrients such as nitrogen and phosphorus.

the science education equivalent of mycorrhizae – a highly important member of the community currently operating below the radar.

Without question, the health and wellbeing of trees is vital to the health and wellbeing of the forest, but the presence of trees in general does not make a healthy forest. The value of the trees to the forest system lies not just in their role as a source of food and general ground cover but equally in the diversity of habitats and resources that they provide for other creatures. This is why veteran trees, with their abundance of dead wood, epiphytes and other complexities, provide a disproportionate value to the forest community: they afford other organisms complex niches; this is so despite the fact that they probably are not the most productive trees in the forest in terms of the amount of carbon they fix and fruits they produce. Thus, although virtually all life in the forest at some level utilises and depends upon these trees for food, it is the presence of these veteran trees and the complex interactions they permit that turns out to be critical to the forest's health and stability. This is why, for example, monoculture timber plantations of young pine trees, though highly productive and generally quite structurally 'forest-like' in appearance, are actually quite barren communities as they afford minimal ecological complexity and diversity.

Quite analogously, our data suggest that schools are highly utilised by many, if not most members of the science education community in the UK. But the question is whether those interactions are multi-dimensional or more narrowly one-way. We know that many informal organisations interact with schools for primarily structural reasons, driven by a desire to gain access to the resource they control – children. Since the vast majority of children between the ages of roughly five and 18 years attend school, schools represent a ready, often essential gateway to those seeking to influence the science interest, engagement or learning of these age groups. The question that emerges from our analogy, then, is whether the schools within the system function more like a monoculture of a timber plantation, affording an important but limited suite of benefits to the community, or more like the veteran trees in an established forest, supplying multiple and diverse resources to the community.

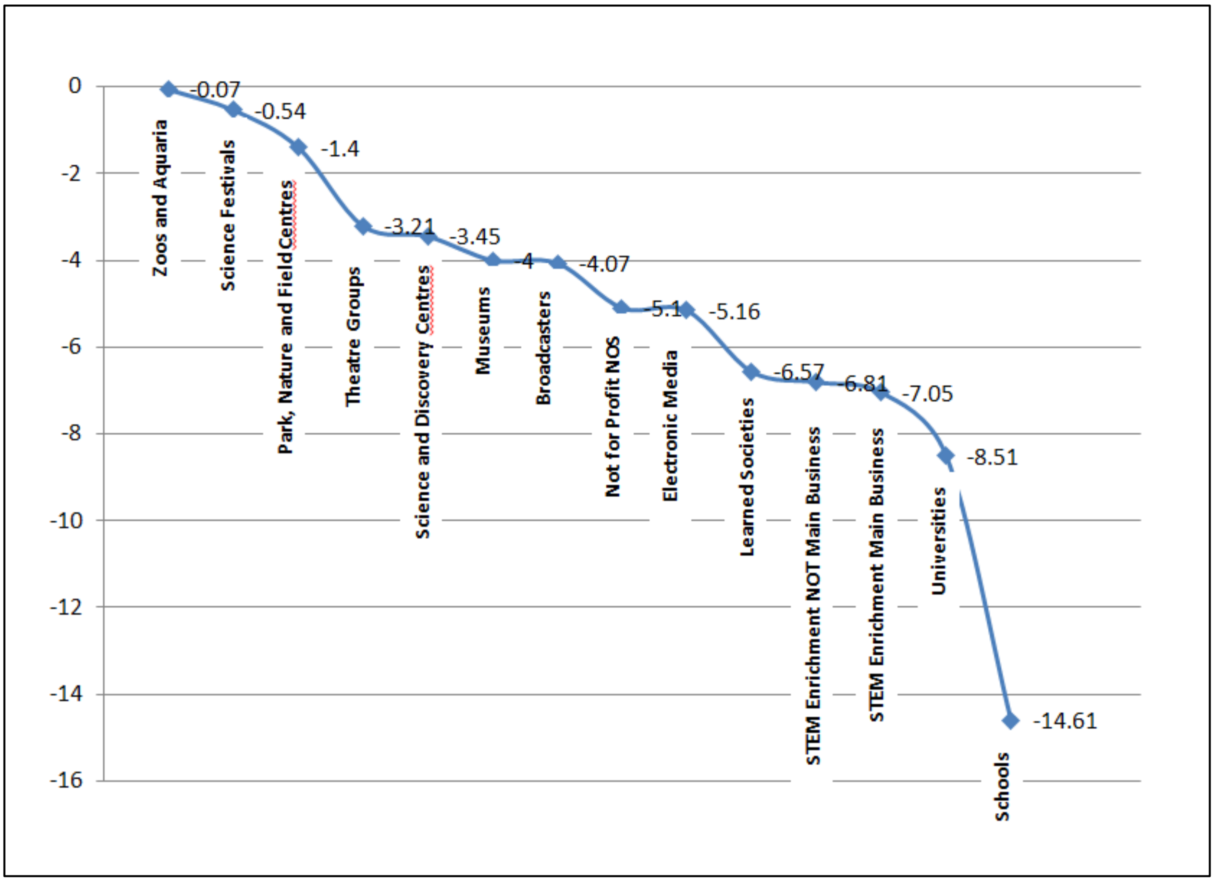
Returning then to the question of who within the UK science education community is important, the answer probably has less to do with the size and conspicuousness of a functional group and ultimately more to do with its role in regulating the flow and wellbeing of the system as a whole. In addition to being asked about who they thought was important, respondents were asked to rate their interactions with members of their own sector, as well as interactions with other sectors. The results of our analysis were as follows:

- All sectors, except schools, reported frequently collaborating with other organisations within their own sector (mean score of 3.78 out of 4 with a variance of 0.05).
- Compared to other sectors, schools reported collaborating less frequently with each other (2.62 out of 4).
- Overall, collaborations across the sectors in the sample had a mean score of 2.94 out of 4 (variance of 0.42).
- Nearly all informal sectors reported working/collaborating with schools. In contrast, schools reported only occasionally and only weakly working/collaborating with informal organisations.

The data suggest that, overall, the UK science education community is highly interconnected. At least among the sectors sampled, all are highly mutualistic within their own group, and moderately mutualistic with collections of organisations beyond their own sector. The major outlier to this generalisation was the schools sector. The two dozen schools in our sample acknowledged that they were the recipients of considerable attention from others but they did not seem to actively initiate collaboration with anyone else, including other schools. We have attempted to depict these interactions in two different ways.

First, figure 6 shows how reciprocal the interactions are for different types of organisation; this is a measure of the intensity of interactivity. It compares: the scores allocated to survey respondents from each given type of organisation based on who they said they worked with; with the scores generated from respondents from other types of organisation based on how much they said that they worked with this particular type of organisation. A score near zero indicates that organisations of that type give about as much attention as they receive (i.e. reciprocity), while a larger negative score indicates that an organisation receives more attention than it gives (i.e. more one-sided interactions). To the left of the figure are groups like science festivals, zoos and aquariums, which appear to generate very little unreciprocated interaction with others in the system. That is, the score allocated for the number of providers they said they worked with differed little from the score given for the number of people who said they worked with them. Also toward this end of the scale are parks, nature and field centres. Collectively, these groups seem to give as much as they get. As we move further to the right, the imbalance of interaction increases. Schools are at the extreme of this interaction flow, mostly receiving attention and giving little.

Figure 6: Unreciprocated flow of interaction/attention within the UK science education community (0 on the Y axis represents equal reciprocation with others, a negative number an imbalance *towards* the institution labelled)



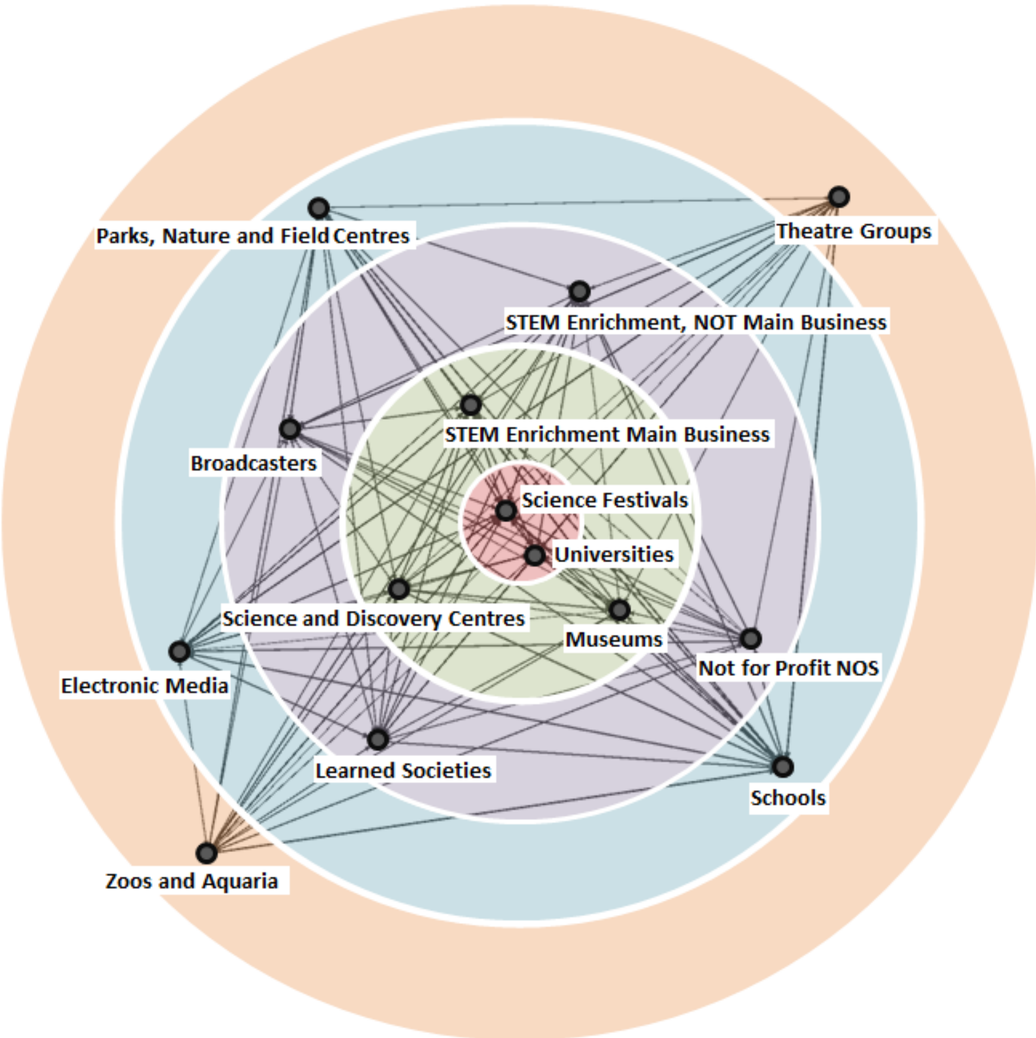
In stark contrast to the measure of intensity of interaction shown in figure 6, figure 7 shows the quantity of interactions existing between organisations; the greater the number of other organisations interacted with, the closer the organisation was to the centre of the figure. So, for example, universities interacted with a significant number of organisations within the community despite the fact that it appears that many of these interactions were relatively superficial, or even one-way, as suggested in figure 6. Some groups, although not necessarily as 'conspicuous' as schools, seem to live at the centre of interactions within the UK science education community. The sectors in the centre of figure 7 are the most interconnected, followed by those in the next ring out, and so on, with the least reciprocally interdependent sectors in the outer ring; by this analysis, those sectors in the middle circles are the most integral and central to the community and those in the outer circles are the most peripheral.[37]

Looking at the community from this interactional perspective, schools emerged as one of the more peripheral sectors, while science festivals and universities appeared to be very much

37 Again, caution should be used in interpreting these figures since the questions asked in the survey were purposefully designed to be generic rather than specific. We did not ask respondents to describe specific collaborations or the causes/drivers of those collaborations, but rather the more generic question of whom they collaborate with and how frequently.

at the hub[38]. Also highly interconnected with the broader community were science and discovery centres, museums and the catch-all category of 'organisations that provide STEM engagement and enhancement activities'. Broadcasters, like schools, voted by many as one of the most important science education providers within the UK, were less centrally engaged in the community, falling farther towards the edge the diagram.

Figure 7: Quantity of interactions among UK science education sectors – greatest interactivity in the middle



38 One reason that universities may appear at the centre could be because of the recent RCUK Beacons of Public Engagement initiative, which has enabled them to grow as a species, so to speak, and occupy a more prominent position (though only a small minority of HEIs were such Beacons). Given the snapshot nature of our current data, we have no way of determining if the current position of universities is a short-term aberration or a more permanent fixture of the community.

The analysis shown in figure 7 provides a big picture, essentially a 10 000-foot view of the interaction networks within the UK science education community; from this view, the sectors are highly integrated. However, a closer view reveals much more complex and nuanced picture. The patterns in figure 7 mean that at least one member of every sector sampled (at least within this initial sorting into 18 categories) was quite involved in one way or another with at least one member of every other sector. This does not mean that every institution within these sectors was interacting with every other sector; in fact, this was rarely the case. There was considerable variability among the individual organisations sampled in each of the sectors. Figures 8 and 9 show examples of the interactions from a random sampling of four organisations selected from each of two representative sectors: learned societies (figure 8) and museums (figure 9).

Figure 8: Examples of four randomly selected community interaction profiles of learned society respondents (bigger circles, closer to the centre, indicate greater reciprocal interaction)

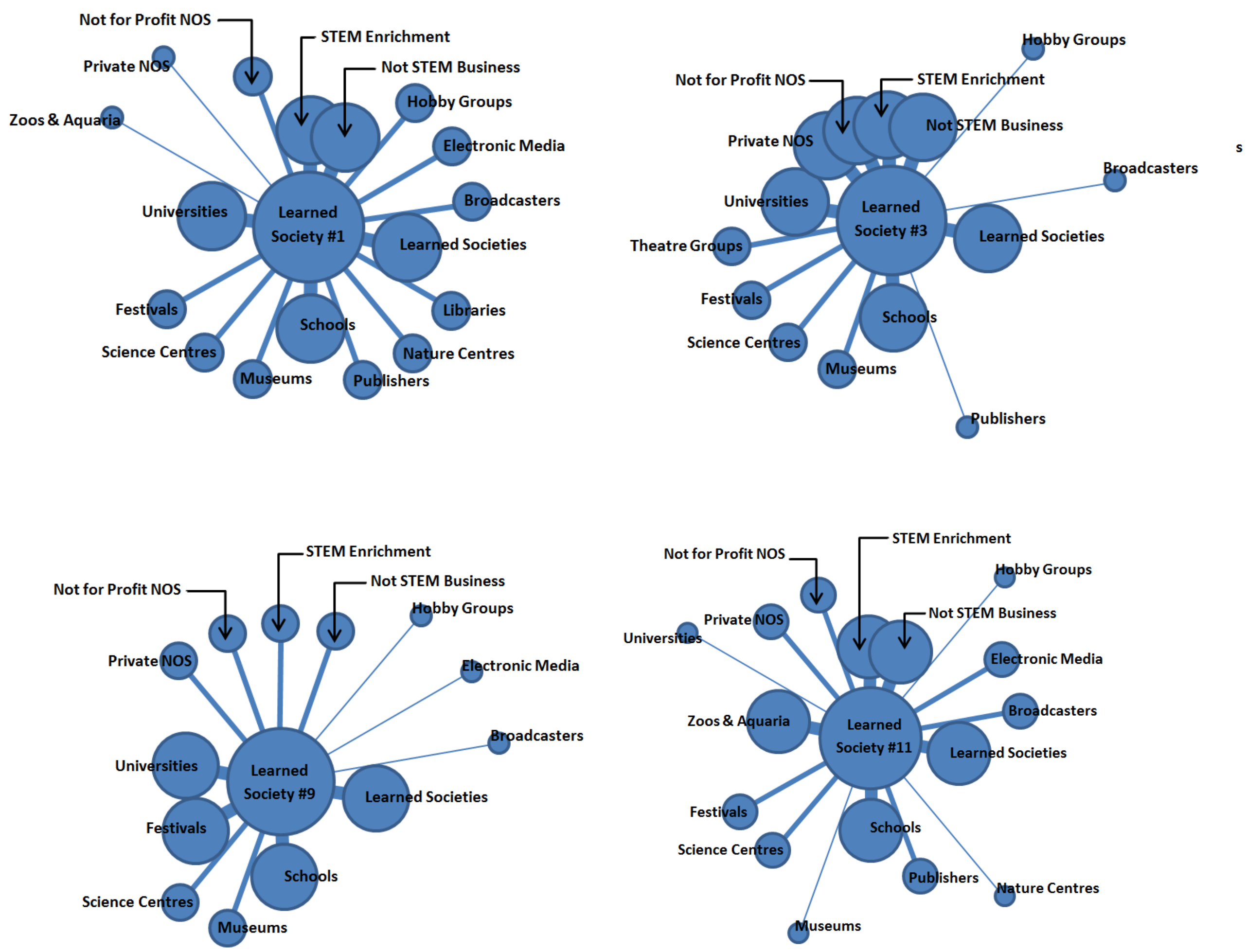
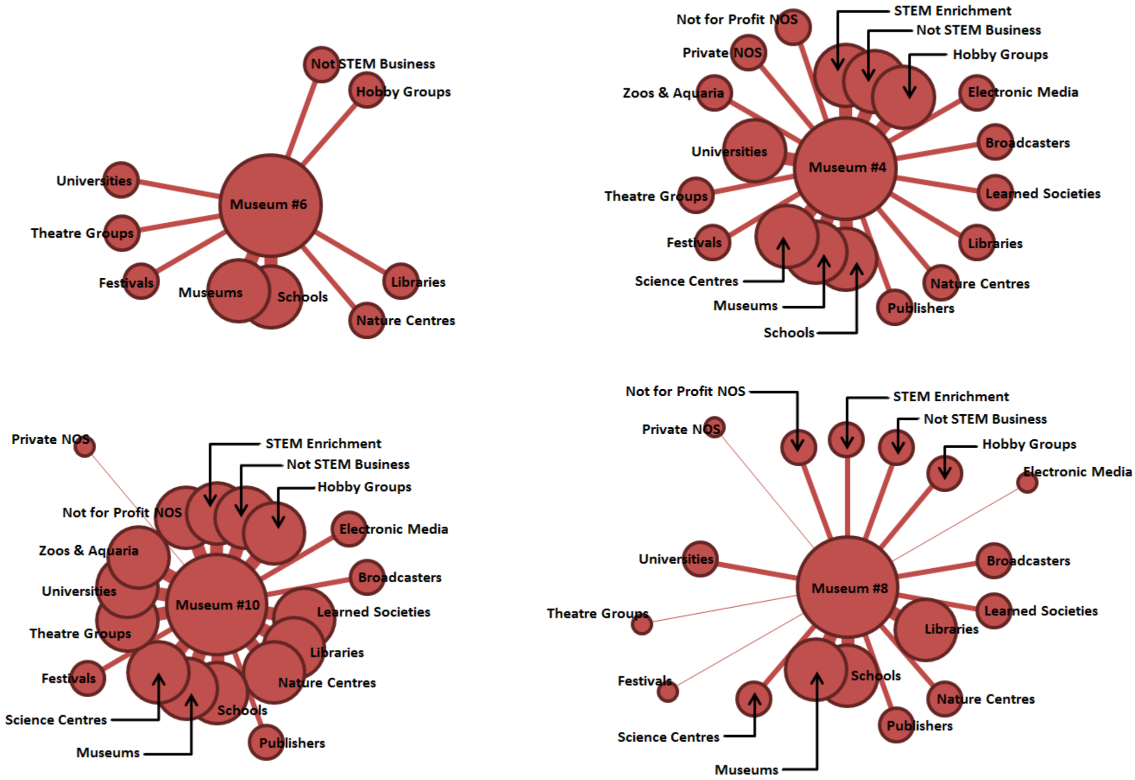


Figure 9: Examples of four randomly selected community interaction profiles of museum respondents (bigger circles, closer to the centre, indicate greater reciprocal interaction)



As can be seen, some organisations were highly reciprocally interactive and others were not, and which types of other organisation were interacted with varied considerably within and between sectors. However, by combining results from figures 6 and 7, science festivals, science and discovery centres and museums emerge as potential keystone sectors.

2.3 What drives the UK science education community?

Ecologists frequently utilise energy flow as a way to make sense of what's going on in a community such as a forest. Energy flow is influenced by both endogenous and exogenous factors. Endogenous factors are internal resources generated from within the system, while exogenous factors are resources that come into the system from outside. Both endogenous and exogenous factors exert influence on the way a community, and the ecosystem as a whole, operates. At the base of the forest energy pyramid are a vast array of photosynthetic organisms including conspicuous organisms like trees but also myriad smaller organisms like algae, ferns and various forest floor plants. These photosynthetic organisms capture the exogenous energy of the sun and serve as an endogenous food source for other consuming organisms of all types, again ranging in size from predacious microorganisms to large ungulates like deer and foraging swine. As is the case in most terrestrial communities, insects are a dominant component. These herbivores in turn are consumed by predators, again ranging in size from the microscopic to large predators like humans.

Like the forest, the UK science education system also has an energy flow, fuelled both endogenously and exogenously. The ‘organisms’ in the community – be they schools, science centres, broadcasters like the BBC or single individuals running science assemblies – are fuelled endogenously by the dedicated people that work within the community. They are the assets and social capital of the system, fuelling its intellectual capacity and innovation. In addition, though, there is an important exogenous resource: the funding coming into the system from outside. Like all aspects of a community, these factors interact. The dedicated people are there in part because of the possibility of paid employment. Although education of the public is the goal, this is not what drives the system entirely; in the absence of funding, (almost) no one would be doing anything. Thus, if we want to manage the system to maximise the public’s learning, engagement and interest in science, much as we might want to manage the New Forest National Park to maximise its value as a recreational site, we need to attend to the overall health of the whole system – by supporting the people who work in it intellectually, socially and emotionally, but also through the judicious expenditure of funds.

By following the funding and the intellectual assets of the people working within the UK science education system, rather than just the learners, it is possible to get a better understanding of the current structure and functioning of the system. For one thing, this makes it easier to see how the system is organised. There are myriad groups of organisms within the system that have evolved to support and, on occasion, exploit the system. For example, integral to the system are specialist organisations that focus on niche activities such as curriculum development or evaluation, even though they may rarely or never actually work directly with learners. Collectively, these specialists make the system richer and enable the ‘producers’ to do a better job. As has been true throughout the history of the New Forest, there are opportunists who successfully swoop into the system when resources are plentiful and disappear when the resources are scarce. The analogues within the science education community might be consultants and university researchers. Finally, there are a host of ancillary groups that are supported by the community, in fact are fundamental to the health of the community, but only very indirectly contribute to the larger, shared goals of the community such as public science education. For example, every sector within the system, but particularly the larger groups such as schools, the BBC and major science and discovery centres, enlist an army of other groups to help them accomplish myriad tasks necessary for surviving within the broader ecosystem. These ancillary groups include barristers, accountants and tradespeople. A thorough analysis of the UK science education system through the lenses of money and intellectual capital has yet to be conducted (though the literature review in the next section represents an important first step), but arguably such an analysis would provide a useful way to better understand the intricacies of the system.

A major goal of the UK science education system is to enhance the public’s science learning, interest and engagement. As is true of ecological communities, more complex, integrated and collaborative systems tend to be healthier and more productive.[39] However, as shown in section 2.2, the UK science education community appears to not always be functioning in ways that would suggest that it is a fully integrated and collaborative

39 Mahonge C. Co-managing complex social-ecological systems in Tanzania. The case of Lake Jipe wetland. E-book. Wageningen, The Netherlands: Wageningen Academic Publishers; 2010.

community; some members, some of the time, are highly collaborative and appear mindful of the value of interactions, while others are less so. And if we want to maximise the quality and quantity of learning as a ‘resource’ we need to figure out how to best ‘feed’ and ‘manage’ both the endogenous and exogenous factors to support more collaboration. For example, it may turn out that encouraging schools to function more like the highly interconnected keystone veteran trees than like isolated, minimally interactive plantation crops might yield more ‘learning’. It also may turn out that some relatively quiet and generally under-appreciated science education sector could be playing a significant integrative role, much like mycorrhizae. For example, could science festivals be playing such an integrative role? However, as outlined in recommendation 2 at the end of this report, the first step is to develop a better understanding of the nature and contribution of all the groups currently supporting science education within the UK. Collectively, this analysis suggests the fundamental role that more management could play in the maintenance of a healthy system – recommendations 3 and 5. Arguably, its role could be framed as trying to prevent inhomogeneity and lack of diversity that may threaten the health of the system, leading to the dominance of certain communities and a failure to work symbiotically. In particular, it suggests examining the nature of the diversity of provision, the extent to which different communities are or are not served, and the extent to which the individual members recognise the goals of the broader system and work to support them in a collaborative manner.

3. The knowledge base of non-school science education

Any self-sustaining professional body, as well as any ecological system, depends on a knowledge base that is passed on from generation to generation. In that sense, the knowledge base is one of the endogenous factors that supports the system. In the case of human systems, such knowledge is generally produced by individuals who work as practitioners within the system and by external individuals who have a scholarly interest in the system. Knowledge is then stored in a form that is accessible to new members of the profession and used to build and improve the theoretical principles and knowledge that guides practice. In the case of learning science in the informal sector, two forms of published knowledge commonly exist – studies that have been published in peer-reviewed academic journals, and studies that are the result of internal or external evaluations of specific exhibitions or activities or other commissioned reports such as this. The latter are commonly known as 'grey literature'. Given the importance of a knowledge base to building the professional expertise, theories and ideas that guide practice, we wanted to know the extent and major features of the literature, whether members of the community were aware of its existence, and how this literature was used.

Hence, a review of published, peer-reviewed academic literature for the field of informal science learning was undertaken. A series of structured searches based on combinations of key terms was used to search two key databases of academic journals (ISI Web of Knowledge and CSA Illumina) for relevant articles published between 1980 and 2011 (see Appendix 1 for full details). The results of these searches were then checked against existing literature reviews and relevant books about the learning of science in informal contexts and supplemented as appropriate. These searches initially generated 4552 articles. Using the title and abstract, each paper was then examined to determine whether it was appropriately related to science and learning. If the paper was, it was included – as long as it was relevant in any sense to the learning of science in the UK. For instance, a paper about science clubs in the USA was included but a paper about public health programmes in Malawi and their outcomes was not included. The final database contained 553 articles.[40]

The articles in the database were then analysed in two stages. In the first stage, articles were read and categorised by two researchers independently under the following six themes: year, sector, participants, location, literature type and research method. Where there was disagreement between the researchers, their categorisation was resolved by discussion. The articles were then read to identify the different theories, research methods and context of investigation. To conduct a more detailed and more manageable analysis in the time available, the papers were sorted by number of citations in Google Scholar. The top 10 per cent – those with 80 citations or more – were then analysed by two researchers. In this stage, all of the articles were read to identify the theoretical frameworks, the research methodologies and the principal findings. This analysis has enabled us to identify the following features of the knowledge base about learning science in informal environments.

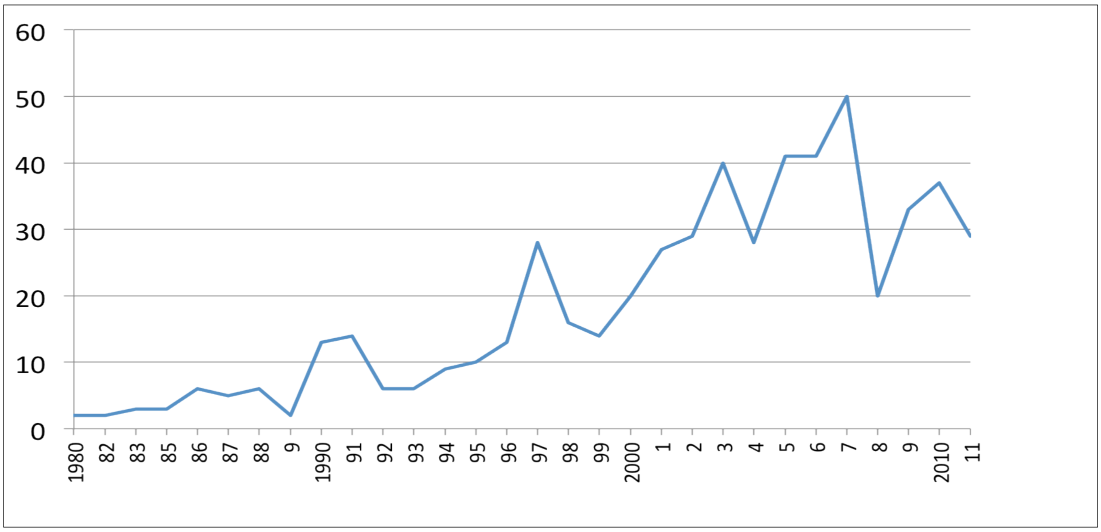
40 This is an Endnote Database which is available from the Wellcome Trust.

3.1 The literature base

The first major finding to be drawn from this analysis is that there is a considerable body of research in this field. Publications on informal science learning appear to have increased substantially from 1980 onwards, as shown in figure 10, with a recent decline.

More than half of the 553 articles analysed were published in three journals: *Science Education*, the *International Journal of Science Education*, and the *Journal of Research in Science Teaching*. It should be noted, however, that remaining articles were published in more than 200 other journals, which is suggestive that the study of learning and engagement of science in informal contexts is undertaken across a broad range of disciplines.

Figure 10: Number of published articles on learning science in informal environments from 1980 to 2011



The coding of the 60 most cited papers in this literature used a similar framework to that used for the larger database (with 553 entries), albeit with more details. For example, articles were grouped into descriptive categories according to the purpose of the study, the type of article, the research methods used, the types of participants involved and so on. The findings of the study were also categorised into sub-themes such as sample size, research methods (qualitative or quantitative), nature of participants. Fourteen of the top 60 papers were specifically reviews of research on informal science learning, which would indicate that the field has a sufficiently substantive research base and that there are themes that can be identified with this body of scholarship. From our analysis five key themes were identified. These were research on:

- the nature of learning
- learning in museums and science centres
- the use of technology or media for learning in informal contexts
- out-of-school science-related activity
- role of family in science learning.

Each of these is described briefly in more detail beneath.

3.1.1 The nature of learning

Over a third (n=24) of the 60 most cited papers focused on the purpose, value or meaning of informal learning. Articles included here addressed such issues as the educational, policy and theoretical values of informal science learning, as well as the positive role played by informal organisations to support and complement formal science education. Some articles also discussed the role/concept of interest in learning, theoretical ideas about learning and the ways in which culture can shape interpretations of scientific knowledge.

3.1.2 Learning in museums and science centres

The papers (n=11) about learning specifically in museums and/or science centres were extremely diverse. Included in this group were articles which: argued that students would benefit if their experiences in museum were learning/inquiry-oriented rather than task-based; provided empirical evidence for the use of labels in museums as a way of transmitting information to visitors, or for the long-term impact of museum/science centre learning by using follow-up interviews; found that students' science learning in museums can be enhanced by post-visit activities; or argued that personal motivation can influence the levels of science learning in museums and science centres.

3.1.3 Use of technology or media for informal learning

These papers (n=6) focused on the use of technology or media for informal learning, particularly on the value of the internet as a source of information. The context here would appear to be mainly the role of technology for the purposes of acquiring health-related knowledge. Findings suggest that use of the internet is stratified by inequalities in education, age, class and ethnicity: those who are better-educated, employed and younger were more likely to use the internet for health information than older, poorer and minority ethnic people.

One study in this set found that the viewing of television in general has a negative impact on people's knowledge about science. However, use of other media, such as newspapers, science documentaries and magazines, was found to generally promote positive perceptions of science.

3.1.4 Out-of-school science-related activity

This body of literature (n=12) explored the learning of science that took place outside the classroom but not in museums or science centres. A broad range of topics was covered. There were, however, no prevalent subthemes. These papers included studies about the underdevelopment of science parks, young people's learning of mathematics in the streets, and the positive influence on students' academic attainment of their participation in extracurricular activities (e.g. science clubs, athletic teams, orchestras). Other findings were that pre-visit preparation for field trips can enhance student learning by reducing the novelty factor and that the teaching of science through an inquiry-based approach in out-of-school contexts can encourage students to stay motivated and interested in their studies.

A few studies (n=4) focused on people's participation in environmental activities, finding that early exposure to wilderness positively influences children's interests in environmental activities and engagement. However, it is younger people with higher education and from a higher social class who are generally more likely to engage in (or have positive views towards) environmental activities.

3.1.5 Role of family in science learning

A small number of studies (n=5) looked into the role of the family in science learning. The articles here focused on the teaching of science to children by families, either at home or during museum visits. Children who engaged in shared scientific thinking with their parents in museum visits were found to generally spend longer at exhibits and had greater opportunity to learn than children who visited with their peers or by themselves. Children's learning experiences in museums were found to be enhanced significantly by parents who interact meaningfully with children and provide 'casual explanations' to children's questions. However, parental teaching of science to children may be influenced by gender, as parents (particularly fathers) tend to hold stereotypical expectations regarding their children's interest in science and ability, with more encouragement shown to boys.

3.1.6 Gaps in the literature

Notable lacunae in this body of work were scholarship that drew on a body of work conducted in the public engagement with science and science communication, and scholarship that explored the learning or engagement with science of women, minority ethnic groups or adults. In addition, very little of this work seems to draw on a considerable body of scholarship conducted on the practices, values and nature of science. These absences raise the questions of whether the field would benefit from more of its papers having a broader sense of the field that they represent and how such a sense could be achieved. In addition, all of this research is conducted on isolated elements of the system and virtually none has attempted to chart the inter-relationships between elements in the system. To extend the analogy advanced in section 2.2, it is as if the research to date had been done on the individual species of the forest, each study isolating a small snapshot of time and space. Almost totally absent are studies that look at groups of organisms and their interaction within and across the wider community.

3.2 Dominant theoretical frameworks in the most cited literature

Fifty-one of the most cited 60 papers had clearly identifiable theoretical frameworks. Broadly these were of a social constructivist nature that sees learning as a product of a process of deliberative and discursive interactions with others – interactions which then enable the individual to construct new understandings and mental models of the world. Within the work there was some reference to key educational theorists such as Piaget (n=6), Vygotsky (n=7), Bruner (n=8), Dewey (n=5) and Gardner (n=9). In addition, within these papers the names of Lynn Dierking (n=23), John Falk (n=28), Arthur Lucas (n=11) and Paulette McManus (n=18) occurred a sufficient number of times to suggest that they had established their work as key empirical and/or theoretical contributions to the field. Other individuals recognised within the informal field, but not to the same extent within the most cited papers were individuals such as Kirsten Ellenbogen, Kevin Crowley, Doris Ash, Jrene Rahm, Gill Noam, Steve Bitgood, Beverley Serrell, Sue Allen, Josh Gutwill and Minda Borun. Notably all of this second group of names are North American and all bar one are from the USA.

3.3 International comparisons

Between 1980 and 2011 the US researchers were responsible for 50 per cent of the published research on informal science learning while the UK produced 14 per cent of the published output. By comparison to international publishing trends for scientific research between 2004 and 2008, the USA was responsible for 21 per cent of scientific articles published, compared to 7 per cent from the UK.[41] Research appears to be dominated by work in the USA, the UK and Australia, with a small number of contributions from a wide range of other countries. In one sense, the contribution of the UK to establishing the knowledge base of the field is significant. However, the absence of any notable active researchers (see previous section) is a matter of concern, as the endogenous UK system that supports the learning of STEM subjects in informal contexts has few individuals who can provide ready access to current knowledge, provide advice and consultancy, or undertake rigorous and systematic studies.

3.4 Research methods

Of the 553 articles reviewed, more reported using qualitative research methods than quantitative research methods (see table 1). In contrast, in the top 60 most cited papers quantitative research methods were used more. From the ecological perspective we draw on for this report, this finding is not surprising as, like any community, there are a large number of elements that interact in complex ways. Insight into the nature of how such complexity operates is probably best obtained by high-resolution, focused studies provided by qualitative research while quantitative studies provide evidence of distinct patterns within the system and its outcomes.

Thus, to date, our understanding of how the system functions has predominantly been dependent on detailed study of isolated elements, through both qualitative and quantitative methods. Qualitative research can provide deep insights into elements of complex systems and how they function; quantitative research can provide broader, more generalisable perspectives and is thus seen to have greater external validity.

In addition, it should be noted that this is still a young field. Thus many of the studies have been essentially descriptive, attempting to document what is happening in and around 'the forest' and, through the combination of theoretical perspectives and insights provided by qualitative studies, develop deeper insights and understanding. Hence, little of the work seeks to test broader hypotheses as the field has yet to define well the constructs that it values and to develop the instruments to measure them in a valid and reliable manner. The additional complication is that many of the phenomena of interest are very transient or ephemeral and not readily amenable to experimental investigation.

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41 Royal Society. Knowledge, Networks and Nations: Global scientific collaboration in the 21st century. London: Royal Society; 2011.

Table 1: Breakdown of research methods used in the 553 published papers

Research method	Percentage of papers
Qualitative	34%
Quantitative	17%
Mixed methods	13%
Literature review/theoretical	13%
Meta-analysis	1%
Professional experience	8%
No information available	13%

Of note is that 8 per cent of these peer-reviewed articles were published by research-oriented practitioners working in the field as opposed to studies conducted by external researchers. This would suggest that there is a small but committed group of practitioners within the community who recognise the importance of identifying their knowledge of the system and communicating it in a permanent and recoverable form. The questions we ask are whether this number is sufficient and what can be done to encourage more studies that would lead to publishable outcomes. Practitioners in this field deal with a set of everyday imperatives that give little time to reflect or engage in the kind of study necessary for publication. Thus, finding a means to support building the knowledge base endogenously may be an important way of strengthening the system.

3.5 The contexts for the research

As mentioned previously, in all, 31 distinct contexts were identified within the research. The four most researched contexts were science museums (67), electronic media (not including TV) (55), science and discovery centres, including planetaria (51), and general museums that were not science-specific (51). The prominence of electronic media suggests that it is an emerging context for research on the learning of science in informal contexts. Notably this contribution and its significance were identified by schools and broadcasters in our survey. Others, however, failed to recognise the contribution of electronic media formats for learning and engaging with science.

The major finding from this analysis is that research is dominated by work in a very limited set of contexts that have been fairly extensively researched. Hence our knowledge of the system is essentially very patchy and there are many sectors about which little is known, such as the role of hobby clubs and science festivals in stimulating and sustaining interest in science. These findings reinforce earlier comments that currently there appears to be a distorted picture of the system with potentially too much significance ascribed to the largest actors, too much attention paid to that which has been studied more extensively, and too little attention to that about which we know little. A more detailed study of the elements within the system, the contribution they make and their interdependence would provide a higherresolution picture and offer a deeper understanding for those who support and sustain the system. Questions that are worthy of further investigation are discussed at the end of the report.

3.6 Who is researched?

Our analysis showed that there was a concentration of research on particular groups of people. In particular, those associated with schools (133 papers), including teachers (36 papers) and school students at both the primary (32 papers) and secondary (65 papers) levels. Research on people who were 'visitors' to museums, science centres and similar institutions was found in 91 studies and families were the focus of 48 studies. A third (178) of the studies specifically focused on investigating the participation of young people age 16 or under.

These findings suggest that a body of knowledge has been established about the learning and interactions of some groups of the population in some informal contexts for science – for example, what school students do in museums and science centres. However, this finding also highlights how little is known about other groups. Very few papers focused on minority ethnic students (8 papers), female students (10 papers), female minority ethnic students (2 papers), low-income students (1 paper), low-income families (1 paper) or minority ethnic families (3 papers). Furthermore, the concentration of research on young people and school students highlights the smaller amount of research available on adults involved in informal science learning, especially women. The absence of studies exploring the learning or engagement of women or girls is particularly surprising given the concern about their lower rates of participation in STEM, particularly the physical sciences, and the extensive body of work that has been conducted in the formal part of the community to understand how to better engage girls and women with STEM.

From a systems perspective, it would appear that only the individuals that participate in the most conspicuous informal venues get studied. Clearly it is much harder to study those that are difficult to identify or those who participate in niches that are not easily accessible. A consequence, however, is that their absence is not detected. Such research runs a risk of establishing an internal logic where those who count within the system are only those who can be counted. The absence of knowledge about the groups who do not visit, or who participate in only the more hidden places in the system, leads to sustaining an ecological community that is less diverse and, in particular, less resilient to changes that are occurring in the wider ecosystem. For instance, if visiting science centres is predominantly undertaken by white, middle-class families, such centres may be threatened if the UK population becomes more diverse, as their social legitimacy will be undermined. Moreover, as previously discussed, if the diversity and richness of young people's experiences contribute to their engagement with science, providing such experiences to disadvantaged and low SES communities is an important means of improving their engagement with learning in schools and ultimately their attainment, benefiting both the individual and the country, which needs to improve the educational attainment of the populace as a whole.

Similarly, if vast numbers of adults are engaged in various hobby clubs that directly or indirectly support public understanding of science (e.g., gardening, bird watching, astronomy) but are 'below the radar', these groups are likely to be under-supported. While the challenge of researching the needs of a more diverse range of groups and how to provide for them is considerable, such knowledge may be crucial not only to assisting the system in how it might address the needs of those who do not participate, but also in enabling the system that supports the learning of science in such informal contexts to adapt and grow and, in so doing, establishing its cultural value to a broader cross-section of society.

In summary, the following are the major points to be made about the research and scholarship on informal learning:

- There does exist a substantive body of empirical work and scholarship that addresses the field of learning science in informal contexts, but there are notable gaps.
- The field does have a theoretical base that draws on many of the ideas developed in research in formal education.
- There are a few researchers in the field whose names arise with sufficient frequency to suggest that they have built a body of recognised scholarship.
- Research and scholarship in the field has been conducted within a very large number of disparate disciplines, making it difficult to locate and identify.

3.7 How well known is this literature?

One question of interest was the extent to which 'practitioners' in the field were aware of any of this literature. If the knowledge base is seen as one of the endogenous 'nutrients' essential to enabling the system to thrive and grow, there is a problem if it is not read or known about, or, alternatively, if it is read but found to be of little value.

At a symposium of key practitioners invited to the Wellcome Trust on 8 May 2012 to discuss issues raised by the research, participants were asked to complete a questionnaire which asked if they either recognised or had read any of the top ten cited papers or any of the top ten journals in our literature review. This list was also augmented by a selection of recent key books that are not counted by citation databases. The full list is shown in Appendix 2.

Twenty-nine responses were obtained from individuals representing 18 different sectors – the largest number being from science centres. The modal (most common) value for how many individuals had read each publication was zero and the modal value for how many recognised but had not read each publication was two. The most read article had been read by less than 50 per cent of these key practitioners (11 people).

Included also was an open-ended question asking participants what they did read. Three-quarters (21) of the participants listed a range of sources of support, information and interest that they drew on in their work. Commonly mentioned were policy documents, evaluations and online resources – largely a 'grey literature'. Eight participants did not give any response to the questionnaire. Participants were also asked which journals they read or had heard of – a list which was supplemented by three well-known online platforms for disseminating findings within the informal science community. More than 50 per cent stated they had read the ASDC newsletter and website, the ECSITE newsletter and website and the journal

Public Understanding of Science. The latter is surprising as only one article in our top 60 cited articles had been published in this journal and only 24 out of the total 553 in our database. That the most widely read journal by these key practitioners is from the field of science communication, which is dominated by issues of public engagement, science and society policy, and media analysis (none of which were the major themes found in the literature review) suggests a mismatch between the interests of the group and the established scholarship within the field. This invites the question of why the field appears not to read the literature specific to the field but does read that produced by a science communication journal.

In one sense, this should not be a matter of concern. A survey of formal educators about the literature in educational research would most likely generate similar findings. However, many of the individuals attending this seminar were senior figures within the field and a comment made during the discussion at this seminar by a participant, who had neither read nor recognised any of the papers or journals on the questionnaire, is revealing:

> Most of the time I read very recent academic publications in the research sciences, when running [name of institution], but as a scientist I'd like to do a controlled test, clone children, give one the best and give one the worst and see where they are in two years. But we can't do that. I saw your list they looked old, not like biomedical research. Why don't we have an open access journal, people here could write amazing papers, maybe without the jargon. But this in many ways isn't rocket science is it? Why can't we just write some papers about it, is there a market, a space for some kind of journal that's about communication? I don't know.

While acknowledging the need for rigorous, systematic and peer-reviewed research within science, this comment reflects a view that does not recognise the distinction between research in science and research in social sciences. In social sciences the fact that a paper is 'old' does not necessarily make its findings any less relevant. Moreover, the implication that practitioners should be able to readily write papers carries with it the suggestion that research in social science is seen as less rigorous and, by inference, less valuable. If this view is indicative of a more pervasive attitude in the community, it would imply that the system that supports informal learning has a problem as the knowledge that is learned individually by experimentation and experience is never captured and is undervalued.

Undoubtedly, within individual institutions, as the GHK report shows, considerable work is undertaken to evaluate what is offered and its outcomes. Such work is extremely valuable within an institution, particularly where it helps to identify failings that need remedying. However, if the findings, methods and implications are not more widely shared within the system, it is much more difficult for providers to learn from each other. How, for instance, is the wisdom acquired by one aquarium to be shared with all aquaria across the country? While there may be many informal mechanisms for sharing such knowledge, the hallmark of a professional community such as medicine, law, architecture or social work is that it develops formalised mechanisms for ensuring that such knowledge is recorded and made available to both existing members and new entrants to the field. This helps to reduce the likelihood that new entrants will attempt to reinvent the wheel and increases the likelihood that they will build on and learn from the knowledge established by previous generations. In terms of our analogy, it is as if the forest had no genetic memory and that every new generation of organisms had to figure out by trial and error how to make a living as a tree, deer or woodpecker. The end result is that this would make the system dramatically less resilient and less capable of adapting to change. These comments do not mean that the community is failing to create meaningful experiences or to learn from each other. Rather, we see nothing to suggest that there is anything exceptional about this community compared to other professional communities – all of whom use research as a means to document and develop a professional knowledge base. It is such arguments that have led to our fourth and fifth recommendations.

3.8 The grey literature

One response within the community to such points is that there is body of 'grey literature' that enables the sharing of knowledge within the community. Typically this consists of reports, commissioned for the purpose of evaluation or to explore what is known about a particular topic such as young pupils' views about science education, which have not been peer reviewed.

A sample of ten reports was chosen for review. The sample chosen was opportunistic, as, by its very nature, there is no way of systematically searching for such literature; there is no established repository for what is essentially an eclectic collection of literature. Examples of the literature were chosen because the nature of the topic or the nature of the activity that they reviewed was distinct. Most of this literature was published recently, and there is no way of determining how long it remains in circulation or how it is used by the field as it rarely appears in citation counts. The work reviewed was predominantly done by a mix of individuals or private organisations – both not-for-profit and for-profit. Notable was the absence of any work undertaken by academics from universities.

As a field, social science has established key features for building new knowledge. These are that work should, wherever possible, be theoretically grounded, have clear research questions framed by the previous research and literature, and use rigorous, transparent, well-developed, valid measures. All of these support confidence in the findings. The grey literature was then examined to see to what extent these features were present.

Approximately 50 per cent of the sample stated the research questions, though in some cases this was only stated as a broad aim. Failure to articulate the questions a study seeks to answer is problematic. For, if the reader of such a report has no strong sense of what question the report seeks to answer, they have no framework for judging whether the methods are appropriate and whether the research has achieved its goal. None of the reports provided any rationale for the importance of the work, how it might build on other work that had gone before or an argument for the questions it was addressing (if these were provided). This absence then makes it difficult to judge the significance of the report. Moreover, without an attempt to situate the study in a broader literature, it is difficult to establish its value to the field.

The dominant methodology found in most of these studies was the use of surveys. No rationale was found for why these methods were the most appropriate form to answer the questions or objectives (if stated). Such methods are very good at answering the questions of *what* exists or obtaining a broad picture of what views people might hold about a specific topic – to use our analogy, essentially what is happening 'in the forest'. They are poor at providing any insight into *why* people do or believe what they do – that is, how they are functioning. This is not to criticise the use of surveys but rather to point out that the overwhelming use of such methods places constraints on the kind of information and evidence that the field is capable of producing. Moreover, only a few studies provided the instruments that they used for their work. Hence, it would be very difficult for any individual or institution wishing to repeat the work in their own context to do so based on the available information. Indeed, only two reports were found that considered what the implications for practice might be or made recommendations for the future within the institution in which the study was conducted.

Finally, if the work is to have any value to the system, and not just the individual organisation, it must be easy for individuals who are looking for information to inform their own work and practice to find. All of the pieces of literature reviewed could be found using a Google search if their correct title was used. However, when a search term was used that might approximate to the kind of entry that such an individual might put into Google, only in one instance did the report appear on the first page of Google results. One advantage this literature does have is that it is effectively open source. However, if the community does value it, why is there no central searchable database of this literature available?

While we would not dispute that there is value in this literature for the individual members of the community, helping them to identify whom they serve and how to make it more effective, it cannot and should not be seen as the best means of disseminating the knowledge within the system for the reasons given above. The work lacks the standard methodological rigour and does not meet the standards of peer-reviewed research. At a minimum all such reports should be expected to:

- provide a rationale for the importance of the work and its significance to the institution and the field as a whole
- articulate a clear set of objectives or research questions
- include citations to previous reports or research
- provide a justification for the choice of methods and the chosen sample
- provide appendices for the instruments that they use
- discuss what the implications of the findings are for the institution and, as well, the broader field
- identify what can be learned from failure as, for the field, knowing what not to do is as important as knowing what to do.

A final concern is that much of this research is carried out by people who are not permanent residents of the community, possessing only a short-term commitment to the community and little investment in ensuring that the knowledge is widely disseminated and used to build the expertise within. While there is undoubtedly a role for independent, external evaluation, too much funding of external consultants means that too little attention is given to building centres of expertise in research and evaluation that are closely tied or embedded within the system. Such centres can take a longer-term view of their role and contribution, and be committed to producing valuable and valued knowledge.

4. Current values and perspectives

Another lens on the functioning of the system was provided by a set of 49 interviews conducted with mid-level to senior practitioners drawn from the 17 informal sectors. In addition, two interviews were conducted with science teachers who had a management responsibility for science in their school. The full schedule of questions used in the interviews is provided in appendix 1 of the GHK report. These interviews sought to explore what the aims and vision of the organisation were, which audiences they served, how they evaluated their work,[42] how they saw themselves in relation to other providers in the system, and what models or conceptions of informal learning and good practice they held.

Each of these interviews was transcribed and a set of codes was developed for identifying the main themes expressed. The codes and their definition were tested and revised by three researchers working independently. The outcome provides insights into the aims and visions that frame the professional work of the individuals working in each of these sectors, how they perceive the relationship between formal and informal parts of the community, and the theories and values that inform their work and decision making. The data provide a picture of the characteristic values, tensions and practices that pervade the system, its weaknesses and its strengths. Below, we discuss each of these features in more detail and their possible implications for the system.

4.1 The relationship between the formal and informal parts of the community

As both formal and informal educators share a common goal of supporting STEM learning and developing an appreciation of science and technology, the nature of the relationship between these two groups of educators is important. As one participant commented, the relationship works best when there is a "kind of dialogue between the informal and the formal…on a deep level". A good expression of what that might mean was articulated by one informal provider:

> I think for the children who are switched on by school learning of science, and there are some – we have probably those children, for example, they then need somewhere to go with it. School science will not be enough then for them. Those children will want to go to the Science Museum or join some young scientist's club or they'll want more. I think there's a two-way relationship there hopefully, ideally.

There was some recognition that education in formal contexts offered an extended and repeated experience which provided an opportunity to "build up a body of knowledge", where you had "time with students" and could "really tailor their experiences once you get to know a class". Thus, the formal contributors were able to build:

> A relationship between the teacher and the student. I don't believe that a student sitting at home and randomly reading things on their own is a way for them to successfully

42 Much more extensive detail on the type of evaluation undertaken and its role can be found in the accompanying GHK report.

achieve formal education. The kind where they get degrees and so on, I believe that a teacher is essential to that.

In contrast, education in informal contexts was seen to be about:

> Supporting and cementing the formal learning that's been done…but also for those students who do have a curiosity…offering them the environment where they can take that a subject further and they can get to know other things that they may not cover in the formal session.

However, only a few respondents expressed such sentiments. Rather, in more than half of the interviews, comments were noted that were critical of education in formal contexts. These were often used as a mirror to define the informal community by what it was not. So "in school they're the naughty kid who sits being naughty in the corner, whereas…"; or science in schools is "done with special chemicals which come out of a special cupboard" and "not taught as if it is a creative discipline". The schools were characterised as only interested in students "as people who need to get through the education system" and was too "exam- and results-driven"; teachers were criticised for their lack of training or knowledge of how to engage with the out-of-school contexts – a comment which is particularly ironic given the lack of training and professional development within the informal community[43]. Other such comments were that the formal sector used the provision of the informal community too much as a "carrot" rather than a valuable learning opportunity; that "real learning goes on outside of school"; and that the "learning that you have in school is really memory tricks, teaching you to remember stuff, but not how to use that information". As a result, science in schools was "predictable" and formulaic, presented a narrow range of sciences, lacked the "wow factor" and was "not contemporary, exciting and cutting-edge". By implication, science outside of school was everything that the school learning was not, and school science's use as a foil to define what the informal community offered was fairly pervasive. Defining your identity in terms of *what you are not* does not matter if you can define it in terms of *what you are*, but *d*oes the pervasiveness of 'we're not school' as a strong theme in the data suggest that this community has a problem in defining what are its goals? Or, as we will discuss more fully in the conclusions section, does it argue for a new, more comprehensive and system-focused set of definitions that encompass the breadth and diversity of the entire community, avoiding the overly simplistic formal–informal dichotomy?

As expressed by one respondent, the informal community is inclined to the view that:

> The whole thing [formal education] is just repressive and boring, and we do something far more interesting and there's a gulf between them. We really try and think about what kind of museum…and inspiring environment…is hard to do in the classroom.

Moreover, there was a sense that communicating with the formal community was:

> Quite difficult because we speak different languages to a certain extent. And when we talk about our learning outcomes in terms of skills and values and attitudes…they don't.

43 Tran LU, King H. The professionalization of museum educators: the case in science museums. Museum Management and Curatorship 2007;22(2):131-49.

In turn, criticisms of the informal community were voiced by one teacher: that sometimes it claimed that it could teach in one show the concepts that teachers struggled to teach in weeks and yet lacked any proof to substantiate these claims. Moreover, in the week following their 'show', students could not, as they could in schools, ask for the experience to be repeated or explained again. The result was that this teacher was:

> Not convinced that everything that is described as informal science education necessarily teaches people anything, or is necessarily is an experience from which people learn anything. I often think much of what is described as informal science education is merely entertainment.

Self-criticism from within the informal community was rare. Criticisms that were voiced were that some of the practice lacked a professional base as there was no formal training in the field and it was hard to regulate quality. A critical comment of a stronger nature was that some of it was done by "outreach groups" who were "bloody useless…and simply don't know what they are doing".

Nevertheless, running through many of the comments was a clear emphasis on complementarity. For instance:

> But what is the S and the M in STEM are at large in schools… The E and the T are quite attenuated. Paradoxically, out of schools, the E and T are written large… So we work to amplify the E and the T appropriately, whilst not swapping the S and the M. So that's how our role is outside – the E and the T to be supportive of the S and the M.

4.1.1 Perceptions of the relationship

Two views of this relationship were detected. On the one hand, there was the view expressed, based on research with schools, that the formal part of the community would be disappointed if the informal part ever produced any kind of a boring and traditional curriculum. The message the informal sector received is that what the formal sector "expect you guys to do is add the engagement, the excitement, the motivation that is going to prompt our kids to get more interested in the subject matter". The informal community were also perceived to be:

> Obviously far better resourced to do exciting and interesting things than schools are. If you go into a science centre, you can maybe observe physical phenomena and demonstrations that you can't in school or in a bigger, grander, cleverer kind of way. There are some fantastic people I know who work at, for example, at [named institution]. Those people are incredibly creative, brilliant people who can create exhibits that show you things in the natural world in a way I as a teacher perhaps couldn't.

Moreover, there was recognition by the same teacher that:

> Formal science educators could learn a lot from those people…if they imitated what informal science educators do in terms of the kind of demonstrations they do, the stories they tell, the approaches they take. If they combine that with the other things we have to do as teachers, the more boring things like testing and assessment, then you would see an improvement in classroom teaching. I absolutely believe that.

Indeed, it is these strengths that are valued by the informal educators:

> You'll hear the conversation among the teachers on the sideline, "God, I'd never get away with that in a classroom." You know? So they're doing things that people feel can't be done on the normal route".

Conversely, there was also criticism of informal providers by a teacher for attempting to do things that are better done in schools and failed to play to their strengths:

> So I have worked with people [informal educators]…where they have tried to justify what they do, in terms of hitting curriculum points. If students do this activity that we've devised, they will understand the theory of evolution by natural selection. Really…?

The relationship between formal and informal STEM education is clearly complex. At its worst, the formal community fails to recognise its own limitations and what the informal community provides. Simultaneously, the informal community has a tendency to view the efforts of the formal community in a negative light, defining the value of what formal education does by its failures. When the relationship takes this form, neither side benefits. As one respondent perceptively commented:

> One of the frustrations for us, we have this fantastic offer completely free and a lot of schools don't consider going outside the classroom. I think it's the appreciation and respect of both sectors for each other… However much we put into marketing, it's not under our control – and schools that want to, will, and schools that don't, won't.

There was evidence that teachers do perceive the value of the experiences provided by the informal sector and that they believe they have something to learn from informal providers. There was less evidence that the informal community perceived anything that could be learned from formal science education. Research evidence would suggest, however, that there has never been a strong collaborative relationship between the two major parts of the community[44]. In common with the findings in figure 7, a quite extensive body of research finds that the relationship is one-sided, with informal institutions going to considerable effort to provide resources for pre-visit planning, and activities during and after the visit, which most schools do not use. Rather, schools perceive the informal venues and outside visits as a reward or a treat, where the principal goal for the experience is affective rather than a resource to enhance student learning. Student attention is often unfocused because of the distraction of being in a new environment – which is well-known as the "novelty effect"[45].

From the analogy with the ecology of the New Forest that we draw on, the schools are the dominant structure in the system. They do not see their existence as being dependent on or mutually supported by other members of the community that inhabit the forest. In contrast, the informal providers are clearly aware that they are, at least in part, dependent on schools for their survival. The failure of schools to recognise and capitalise on what the other groups provide is a failure to value the role that diversity and integration play within this complex

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44 DeWitt J, Storksdieck M, A short review of school field trips: key findings from the past and implications for the future. Visitor Studies 2008;11(2):181-97.

Dale-Tunnicliffe S et al. School visits to zoos and museums: a missed educational opportunity? International Journal of Science Education 1997;19(9):1039-56.

45 Falk JH et al. The novel fieldtrip phenomenon: adjustment to novel settings interferes with task learning. Journal of Research in Science Teaching 1978;15(2):127-34.

community and that both they and the other myriad sectors would be collectively enhanced if they were to engage more positively in mutual cooperation and support.

4.2 Audiences

Many of the findings about audience from the analysis of the interview seem to confirm the findings of the GHK report (see table 3.1 in the GHK report). Hence, what we report here are some relevant insights about the perceptions that providers of informal experiences have of their audiences. The dominant audiences discussed by respondents were families (mentioned by 22 respondents) and primary and secondary schools (mentioned respectively by 22 and 23 respondents). The major theme in the discourse about families was one of families learning together. Some providers targeted specific members of the family, i.e. fathers, and some specifically targeted families from disadvantaged communities.

When it came to working with schools, interviewees distinguished between events for primary schools, which were seen as more hands-on, exciting, and fun, and events for secondary schools, which were seen as more challenging, dialogue-based and oriented towards career choices. For institutions like science centres, botanic gardens, science museums or zoos, working with schools included both schools coming to them and their own 'outreach' programmes that took elements of their work to a school.

Teachers were also mentioned by 14 respondents as a specific audience and described in two key ways. First, as a way of reaching the school students that the respondent's organisation was actually interested in, and second as a conduit for improving the science education experiences of students by training teachers or supplying them with better resources. Teachers were essentially perceived as holding a gatekeeping role, controlling access to students, so they were seen as an important audience.

Engaging the general public was also mentioned by 22 of the respondents. Here the tone was quite aspirational, with talk of a desire to reach "as many people as possible", engaging "general audiences" or being open and accessible to everyone. Only a small number mentioned targeting audiences who were less comfortable with science. In addition, the view was expressed that the 16–25 audiences were hard for science centres and museums to engage. One concern expressed was that the sector was driven by a "huge access agenda", resulting in institutions trying to "second-guess what people might be interested in to attract a more diverse audience" rather than "doing the best things possible in the most interesting and delightful way", which worked just as well.

While serving the whole community was a goal shared by many, when asked directly about work with under-served audiences, many interviewees described achieving this goal as difficult, as one that was overwhelming and almost too hard to do anything about. Engaging these groups was a problem because the schools that served them were seen as "dysfunctional", did not have "the headspace to cope with this", or, as was pointed out:

> What is particularly unsuccessful is the schools one's asked to are not the schools that really need external help. That is a structural problem that I don't know how to solve.

In addition, providing for a diversity of audiences was seen by some to be resource-intensive.

Seven of the respondents mentioned specific attempts to provide experiences for children under the age of five. Unlike the USA, where there are hundreds of Children's Museums that focus on a single well-defined group and have a very distinct and different view of their role and the contribution they make to the learning of young children, the UK has only one institution that specifically focuses on this age group. Given the body of evidence about the importance of early learning experiences[46] to learning later in life, it must be asked whether this group of providers is a very under-represented element of the UK provision. The data shown in figure 3 would suggest that it is when compared to the proportion of the population that constitutes the under-five demographic.

If these findings are representative of the community as a whole, then they suggest that the primary focus of many of the institutions is children of age five upwards and young people. One way of explaining this is that schools (the trees) are such a large element of the system that they attract much of the attention and resources. Alternatively, it may simply be that they are easier to work with than other audiences. However, such a focus has a cost: the perception in the public's mind is that such institutions are seen as 'for kids' or 'for families with kids' and not as institutions which offer anything that engages adults or which is of more significant cultural value. The outcome is that messages about the cultural achievement of STEM and its value to the adult society are neglected or devalued. Arguably, then, the system is not putting sufficient resources into engaging a broader adult audience or contributing to establishing the cultural significance of science. This result is also supported by the data shown in figure 3, which suggests that, given the proportion of the population they constitute, adults do not attract their fair share of resources or priority.

4.3 Pedagogy

4.3.1 Ideas and theories about learning

Views about the nature and role of the educational contribution of the informal sector were obtained from a question asking how decisions were made about which activities to offer and whether any theory was used to justify such decisions.

No single identifiable idea about what constitutes good teaching and learning was found. Rather, there were instances where individuals had a clear sense of the philosophy that guided the design of the experiences they offered in order to maximise learning. In many other instances, what guided people seemed to be a mix of their own personal wisdom and pragmatism. Moreover, no particular sector stood out as more or less theoretically driven than the others.

The theory of learning most mentioned, but still only by a small number of interviewees, was constructivism. Broadly speaking, this is the idea that what influences learning most is the learner's prior knowledge, which acts as a filter to make sense of all new experiences. Learners then have to construct an understanding of any given phenomenon for themselves and this requires active effort on their part. While constructivism makes the important point that it is the learner who must do the work to build their own understanding, as an educational theory it has been the subject of extensive criticism – in particular for its failure

46 Melhuish EC. Preschool matters. Science 2011;333:299-300.

to articulate how it distinguishes itself from 'discovery learning' (a concept which also has been extensively critiqued,[47] and for its lack of anything substantive to say about how to teach[48].

Evidence that these confusions exist in how constructivism is interpreted by informal providers could be found in comments that "the underlying theories that we certainly use in this organisation look to guide our work are discovery and constructivism" – a comment which conflates discovery learning and constructivism. Or that:

> We've certainly come from a constructivist point of view in the sense that we are inquiry-based. We're about trying to generate real situations where you can learn from objects. We encourage students to raise questions.

Missing from this comment is any recognition that the asking of questions is only the start of the process of learning and that the quality of questions is dependent on a body of prior knowledge that helps the individual to identify what is salient. Respondents may be aware of these nuances but very few comments were elicited that demonstrated a more sophisticated and complex understanding of theoretical ideas about learning.

A primary pedagogic rationale that several respondents articulated was offering students opportunities to engage in inquiry. Inquiry was seen as being "open-ended" and driven by what the "student wants to do". It provided an opportunity to get learners "doing things for themselves", enabling them to "get the most from exhibits" and develop associated process skills. One respondent went so far as to say that "in as much as we have a pedagogical model, that would be it, really".

Inquiry-based teaching, however, has a long and troubled history, caused by the failure to define adequately what is meant by the term[49] and the confusion that arises between the *doing of science* through inquiry and the *learning of science* through inquiry – activities which have fundamentally different goals. The former seeks to make an original contribution to knowledge while the latter seeks to help the learner understand what is already known. Moreover, much learning requires not just 'hands on', with access to real objects, but 'minds on', in which students engage in reading, writing and talking science as well[50]. Partly for these reasons, current thinking in formal science education now talks less about inquiry and much more about the need to provide students with opportunities to engage in a repertoire of scientific practices[48]. There was, however, no evidence of any awareness of this perspective in the field.

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47 Klahr DC et al. Educational interventions to advance children's scientific thinking. Science 2011;333:971-5.

48 Osborne JF. Beyond constructivism. Science Education 1996;80(1):53-82.

Matthews MR. Constructivism in New Zealand Science Education. Auckland, New Zealand: Dunmore Press; 1993.

49 National Research Council, Committee on a Conceptual Framework for New K-12 Science Education Standards. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: Board on Science Education, Division of Behavioral and Social Sciences and Education, National Research Council; 2012.

50 Gregory R. Science through play. In: Levinson R, Thomas J (eds). Science Today. London: Routledge; 1997. pp. 192-205.

Pearson D et al. Literacy and science: each in the service of the other. Science 2010;328:459-63.

Likewise, one or two respondents mentioned the notion of learning styles as a rationale for what they did, going as far as to claim that this particular perspective on learning had "been proven". In fact, the concept has been the subject of several extensive critiques[51] – partly because of the lack of empirical evidence to justify the concept. The contrast was one respondent who drew extensively on a good knowledge of Falk and Dierking's contextual model of learning[52] to elaborate how she felt the experiences and environment provided by her institution supported learning. This, however, was a notable exception.

These points are made not as a criticism of the field – as similar confusion could be as readily identified from a set of interviews with formal educators – but rather to point to the fact that, for a system which aims to support learning as one of its primary goals, there was little evidence of any deep understanding of contemporary ideas about learning – a finding which is further confirmed by the lack of knowledge or familiarity with the academic literature discussed in section 3.

Indeed, part of the challenge for what has been called the informal sector is that, as suggested by the earlier section that drew on ideas from community ecology, this is not a singular sector but rather dozens of sectors and, as such, possesses a wide diversity of approaches and intended outcomes. There are those who focus on cognitive goals in that the learner might learn something new, those focused on affective goals in that the learner might be stimulated and engaged by their experience, and others focused on behavioural outcomes in that the experience might lead to different activities and behaviours. Occasionally, some address all of these goals. Few schools, for example, ever attempt to achieve such a range of outcomes from isolated, individual experiences. Indeed, it might be said that many providers of educational experiences for learning science would benefit from a more limited and focused set of aspirations. For instance, it was argued that informal institutions were environments that could "release themselves from worrying about the cognitive side" and that:

> Learning outside the classroom should be something fundamentally different for the school that they can't achieve in their own school. It should be active, outdoor, discovery-based, and it should be very much about the learner and not us seeing them as empty vessels whose heads we have to fill with whatever we want to fill.

Thus, informal education provided an opportunity to "look at science in a more free, kind of creative curiosity kind of way" than schools did. Again, such comments are redolent of a view that somehow there is something fundamentally different about learning outside of school and demonstrate a naive view of what happens both in and outside of schools. Good learning in schools is not just active but interactive, with students engaged in critical discussion and the need to produce a meaningful product,[53] and forced to work to construct good models of the phenomenon they are investigating. All parts of the UK science education community need to recognise that, fundamentally, good learning is good learning,

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51 Coffield F et al. Learning styles and pedagogy in post-16 learning. A systematic and critical review. London: Learning and Skills Research Centre; 2004.

52 Falk J, Dierking L. Learning from Museums: Visitor Experiences and the Making of Meaning. Lanham, MD: Altamira; 2000.

53 Chi M. Active-constructive-interactive: a conceptual framework for differentiating learning activities. Topics in Cognitive Science 2009;1:73-105.

regardless of where it happens. Whether a school, broadcast, museum or hobby club experience, all have strengths in terms of how they can achieve this goal and that there is much to be learned from each other.

There was, however, evidence that some individuals did have a deeper understanding of what produced effective learning. Thus, one respondent pointed to the importance and critical role of failure – the need to understand that often things are "neither right or wrong", but rather, the need to "understand that failure" as a means of becoming "productive and positive". This concurs with a considerable body of education literature that suggests that knowing what is wrong matters as much as knowing what is right[54]. The same respondent also pointed to the vital role that disruption has in challenging pre-existing conceptions:

> There's got to be a disruptive element. So whether you are in a school, and you change the environment in the school. You disrupt the classroom. Or you change the desks around. Or you go to a different place to do a lesson than where you normally do the lesson. So you have the science lesson in the drama studio.

Experiences which are disruptive produce cognitive conflict, which is a key strategy in the learning of science. Notably, most of these more sophisticated ideas about learning came from those who had an arts background, arguing that it is essential that there is an "element of provocativeness". This was seen as a vital stimulus to generating questions and dialogue about phenomena, enabling transformative experiences.

The value of trial and failure was very much at the heart of the kind of learning valued by electronic media producers. For these respondents, learning was seen as a:

> Process of experimentation and repetition and learning, through which you gradually build up a picture of the world in the virtual world you are in and how you can best either pass through it, control it, negotiate with it – whichever works. So games, by their very nature, breed experiments.

Persistent failure, however, leads to frustration, and in the case of games design, the art is to provide sufficient information to enable players to learn from their mistakes and build a model of how the game works – something which is often achieved by social interaction with others in online forums[55].

More common among the sample was reference to the value of dialogue as a means of supporting learning. Comments pointed to its value for engagement and for sharing, developing and extending the knowledge that the visitor already has. Given the contemporary emphasis on the role of dialogue for learning in research on formal education which draws on the work of Vygotsky,[56] Wertsch[57] and others[58], the penetration of this work

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54 Oaksford M, Chater N. Bayesian Rationality: the probalistic approach to human reasoning. New York: Oxford University Press; 2007.

55 Gee JP. What video games have to teach us about learning and literacy. Computers in Entertainment 2003;1(1):20.

56 Vygotsky L. Thought and Language. Cambridge, Massachusetts: MIT Press; 1962.

57 Wertsch J. Voices of the Mind: A sociocultural approach to mediated action. Cambridge, MA: Harvard University Press; 1991.

58 Gee J. Social Linguistics and Literacies. 2nd edn. London: Taylor and Francis; 1996.

into the discourse about learning is positive. What is not clear, however, is whether this emphasis on dialogue is a product of a knowledge of educational thinking or, what we think is more likely, whether the emphasis placed on dialogue by those working in the related field of public engagement in science, where it has been a major theme since the publication of the House of Lords report on science and society[59] for somewhat different goals, has seeped into the discussion of learning.

4.3.2 Engagement

A major theme was the value of the informal environment for providing experiences that were engaging or enriching and that inspired and interested learners. As one respondent put it:

> We've learned about engagement to create experiences that are memorable and trying to research what some of the triggers are for those things that make things memorable so that they can help to transform the way that people view the world.

Informal experiences were seen as better able to provide immersive experiences that offered a "powerful way of tapping into people's emotions" or more simply were just "fun". The emphasis on the value of informal experiences for this purpose could be found in comments that this was the "huge, huge power of learning science in these out-of-school environments" or that there was "massive power in theatre". The aspiration was that these inspirational experiences were in some way transformative.

This emphasis, however, was on triggering and stimulating interest (triggered situational interest) rather than maintaining interest (maintained situational interest) such that an individual's interest might become an emerging (emergent individual interest) and finally well-developed or mature interest – all of which are seen as part of the four phases of interest development[60]. In a few instances there was a recognition that there was more to developing interest than just a stimulus. For instance, one respondent pointed out that interest in science had to "be built and sustained" and that the issue of lack of engagement with STEM subjects was:

> Not going to be fixed quickly. So for us, the word "sustained" is vital because the job is hard. And the road is long.

The overwhelming focus on the stimulation of interest as opposed to sustaining or building interest suggests that the field lacks a deeper understanding of interest and the structures that are needed to support its development. Or, to put it another way, it appears that the current strategy of the sectors inhabiting the system is predominantly to focus on short-term influences, momentarily brilliant outcomes, rather than longer-term, sustained impacts. A systemic view, where different parts of the system could build on their strengths to collectively serve the public, seems absent from nearly all the interviews, including those with teachers. Currently there are no system-wide mechanisms that would support individual learners' abilities to draw on or visit multiple sectors across the system.

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59 House of Lords. Science and Society. London: HMSO; 2000.

60 Hidi S, Renninger KA. The four-phase model of interest development. Educational Psychologist 2006;41(2):111-27.

4.3.3 Summary

From this analysis we are led to the conclusion that the system lacks a strong theoretical base to guide what it does, at either the system or the individual level. There is a lack of reflection, for instance, on what is meant by 'fun' or what distinctive features of an experience make it engaging and could be carried from one context to another. There was, for instance, no discussion of any provisions that had been failures – an absence that is puzzling, as there is a lot to be learned from such events. In addition, there are no mechanisms for sharing failure. To draw on our analogy with an ecological community again, knowing why life is scarce or struggling in any part of the forest is as valuable as knowing why life is plentiful and thriving in another part.

There appear to be no programmes of training that would enable new entrants to acquire a basic set of professional knowledge on which they could build. A commonly expressed view was that the strengths of the informal sector were stimulating interest, providing innovative experiences and providing more profound learning because it was experiential and you learned through doing. Broadcasters saw their contribution as one of "imparting knowledge" and "telling people about what one area of the world is doing". Science in the media was "not telling people how to pass exams. It is explaining what the scientific method is". Again, these examples suggest that the field possibly has a need for a deeper understanding of the constructs that drives what it does. For instance, science cannot be learned just through doing but requires learners to engage in talking, thinking, reading and possibly writing; education is more than telling or imparting information and requires individuals to construct their own mental models of the world; there is no singular scientific method but rather a multiplicity of methods and techniques; and rarely is there a magic moment when learning happens – rather it is an ongoing process occurring over time and through multiple experiences.

4.4 Science as part of our culture

The majority of organisations (n=37), from across the sectors, expressed a view that it was one of their goals was to convey "the cultural importance of science". In the views expressed, there was a passion for science and science was considered to be a fundamentally good or worthy thing with which to engage. Moreover, science was seen as being relevant and "part of everybody's life" and "simply a public good". Another perspective was the value of scientific knowledge that provided a set of tools for "exploring the world forever", making people "better equipped to make choices in their everyday lives".

However, there were limited references to the conceptions of science that interviewees were trying to build. Uncertainty was one issue that emerged. Science was "all about asking questions and not necessarily getting to the right definitive answer on a particular thing". Students who were taken out of the classroom had experiences that would help them to see that "the world isn't predictable", that "we are dealing with messy data" and that "all of that scientific methodology which appears to work in beautiful straight-line graphs – doesn't happen outside". A goal, one respondent stated, should be to explore:

> How to assess risk, what is meant by evidence, what science does, what scientific theory and proof mean, those sorts of things that if you can get across a better

> understanding of those things and then people are slightly better able to digest what they read in papers and have that debate down at the pub and think.

Another goal was developing a “scientific habit of mind”, involving a process of experimentation which required the user of a game to construct a picture of the world. Participants’ comments reflected the dominance of the S in STEM; the E and the T were the focus of a few of the respondents but the M was absent. Indeed, very few informal institutions in the UK appear have made any serious attempt to represent or communicate mathematical ideas in an engaging manner.

A handful of organisations saw one of their primary aims as strengthening the supply of future scientists. Hence their emphasis was on providing better information about possible careers and the nature of scientific/engineering work. Organisations with the intent to ‘recruit’ more people into science tended to be STEM-focused organisations and learned societies. The converse of this position was more common and exemplified by broadcasters, who took an egalitarian perspective, emphasising the potential of science to empower everybody.

Only one person suggested that some of the stories that science tells might not only be “incredibly informative” but also “incredibly beautiful”. Such references to what was engaging about science were relatively rare. Absent from any of the comments was a sense of what are the key features that make science fun or exciting – that is, the idea that science forces the asking of intriguing questions about the material world, provides explanations that are simply awesome, and is liberatory in the sense that it offers the possibility of creating new knowledge. For instance, only two respondents out of the whole sample used the words “awe” or “awesome” in their interviews and only five used the word “wonder” to suggest that certain aspects of science had aesthetic value. The lack of explicit recognition of such features would suggest that the community lacks a clear sense or articulation of its goals or a manifesto for science engagement and education – a set of core values which all providers could subscribe to – a kind of scientific creed.

Instead, a few respondents suggested that their practice was to introduce “science by stealth”, suggesting that ideas of science have to be sugar-coated to make them more digestible. As Claude Bernard, the 19th-century physiologist, stated, “science is a hall full of awe and wonder, the problem is the long dark kitchen that you have to go through to get there”. Such comments are indicative of an attempt to bypass the kitchen. Given the foundational emphasis of school-based science education to build the elements of scientific understanding brick by brick, only revealing the full vision for those who stay the course, bypassing the kitchen is in many senses an admirable complementary approach. However, the prevalence of comments about “fun” and “excitement” in the absence of a broader vision of their purpose and function makes many of the organisations represented in these interviews vulnerable to the oft-repeated critique that they are in the business of “info-tainment”[61]. This sentiment was captured by one respondent who said:

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61 Shortland M. No business like show business. Nature 1987;328:213-4.
Self W. This week Will Self has a disastrous museum experience. The Times Magazine 1998;10.
Postman N. Amusing Ourselves to Death: Public discourse in the age of show business. London: Methuen; 1987.

> I have a problem with the word entertainment because it just implies something very superficial. Whereas when I go and see something I really enjoy, it makes me think, and I might learn something. Or it makes me look at things in a different way, and it might be very enjoyable and fun as well.

However, it should be pointed out that the concept of learning by stealth – the need to cloak or conceal what might appear difficult – is not restricted to the informal sector[62].

Without a stronger sense of what science offers humanity and without a stronger sense of its own value, there will always be the lingering criticism that science does little more than explain[63]. One possible explanation of the lack of emphasis on the cultural value of science is that it is rather like asking a squirrel about the importance of trees – the answer might be so self-evident to those in the system that it would simply seem naive. Another is that the dominance of young children or families as primary audiences reduces the need to communicate the cultural significance of science. However, for those who manage the system, understanding what are the features of science they wish to support and sustain is important, and it must remain a matter of concern that there is a lack of a conception of what makes science awesome, wondrous and challenging.

4.5 Science and equity

Most of the responses that explored the role of how institutions could support issues of equity in society were captured by the question that asked whether there were any audiences that were not well-served. Of the 51 interviews analysed, slightly more than half made a comment of note.

4.5.1 Science for all as an ideal

Many of these comments demonstrated a strong commitment to the moral and ethical case for their activities to support and engage with all members of society. For instance, the point was made that many of the institutions are charitable entities, therefore they are legally obliged to engage with underserved communities. Others saw their work as being about the need "to empower people about their own immediate lives and lifestyles to make choices and have a better understanding about what's affecting them right now". In this sense the theme of science for all or science equity can be seen as an ideal, drawn on by interviewees as a core value.

Some interviewees suggested that many sites for engaging people with science informally were a catalyst for bringing together people who differed in education, social class or ethnicity to share common experiences and "make things happen". More specific to science, one provider saw her work as a means to make science appealing to those that formal education had failed to reach. A more instrumental view was expressed by a broadcaster,

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62 Kirby L. Stealth learning: unexpected learning through games. Journal of Instructional Research 2012. www.gcu.edu/Academics/Journal-of-Instructional-Research/-Unexpected-Learning-Opportunities-Through-Games-.php. Accessed September 23, 2012.

63 EM Forster made this point in *Howard's End*: "Science explained people, but could not understand them. After long centuries among the bones and the muscles, it might be advancing to knowledge of the nerves, but this would never give understanding."

who argued that broadcasters had a desire to educate as many people as possible. Such a comment must be tempered by the fact that the primary goal of broadcasting (at least, commercial broadcasting rather than public service broadcasting) is audience engagement, and education of any form is always a subsidiary goal.[64] Nevertheless, what emerges is a strong sense of a community with a strong moral imperative, as expressed by one individual:

> I feel it's what we need to do, you know, because we have this mission to reach all types of people.

In many ways, this value is not surprising as, even in organisations that are private enterprises, their owners commonly have previous experience of working in the public sector – a sector that attracts people with a strong commitment to equity. Appropriate experiences in the informal sector were seen as a way of:

> Working with kids who have had quite a traumatic time, whether they've been in prison or dropped out of school or they've had mental health problems. I know from my experience, if you engage them in a creative project, it will make a difference to that individual's life.

The notion of 'science for all' was interpreted in two distinct ways. Some interviewees focused on the science itself and framed inclusion and access in terms of creating informal science learning or engagement formats that made science appealing, relevant, fun or less difficult and off-putting.

> When people think of science, the thing I used to get a lot in my peer group at university or at school would be I don't get science. Or I find it too hard. So therefore, I don't find it accessible. All it's trying to say is it is accessible. And there's lots of great things about it. And the accessibility does depend on the individual.

A second perspective was that science content could pose problems for some people and that social disadvantages could create difficulties of access for some groups. Aspects of social disadvantage mentioned by interviewees included those relating to gender, ethnicity and disability. However, only one interviewee talked about people with physical or mental disabilities. Moreover, far fewer interviewees went beyond talking about the topic as a value that they believed in and discussed how they implemented such beliefs.

4.5.2 Science and equity in practice

A few interviewees did talk specifically about how they used their resources to serve "audiences we think might be disadvantaged or disempowered in some way". For instance, one talked about how their organisation was specifically building a new centre in an urban location to provide more opportunities for low SES students. This person was able to describe specifically how addressing issues of equity was a concept that affected their strategic planning. Similarly, one museum had developed a range of initiatives and formats for informal learning opportunities that were more inclusive, including provision for

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64 Kirby DA. Scientists on the set: science consultants and the communication of science in visual fiction. Public Understanding of Science 2003;12(3):261-78.

individuals with disabilities e.g., visually or hearing-impaired, as well as opportunities that were designed with issues of gender, ethnicity and SES in mind[65].

However, many interviewees only talked in general terms and were much less specific. For example, an interviewee working in the science centre community suggested that equity was an inherent quality of the opportunities provided by informal contexts:

> Being in a space that's safe to do that…that you could do it and you don't have to retain that good kid, bad kid, whatever you are. You can just enjoy doing it just because it's fun and it's enjoyable.

The lack of specificity, however, may be a product of the way the interviews were conducted, since the questions did not ask for examples. However, another explanation of the absence of examples may be that while equity remains a powerful framing device/discourse among the informal science learning practitioner community, it is far harder to effect such ideals in practice.

4.5.3 Schools as a means of achieving equity

One conduit for achieving science and equity goals was seen to be working with schools. In schools:

> You've got all walks of life in one place, as all these people haven't been excluded from school. So at least you are in with a chance of kind of getting all sectors of society when they're in one place.

Or:

> One of the reasons we have such a high emphasis on schools outreach is really to do with access to what we do because that…driven by a desire to not just reach say better-educated middle-class families…but to reach the more disadvantaged people, the girls, the boys with no confidence.

Schools did not always reciprocate, though, especially when they operated policies that confused the case for equity with the need to treat everybody as equal, by refusing the offer of an engaging experience for their students, arguing that they had "a policy of either something has to be done with all of our pupils or none".

Questions can also be raised about the extent to which schools really do provide a route to deliver equitably informal science learning opportunities. One interviewee described their institution's attempts to engage with schools in "disadvantaged communities" as only partially successful, suggesting that, despite their attempts to target certain schools and teachers, the schools, teachers and ultimately students they served best were from better-resourced areas. In addition, engaging such communities required a disproportionate amount of the institution's resources.

65 This specific museum and what it has done is discussed in more detail in section 3.4.2 of the GHK report.

> I think that we, like many organisations, spend a lot of time worrying how to reach schools, how to reach kids, disadvantaged communities, quite rightly. We also spend a disproportionate amount of reserves on trying to get to those communities.

Or:

> The teachers who aren't in that position, who are from disadvantaged communities or struggling to engage with our programmes, we find it more difficult to serve them because they need lots of handholding and that's very expensive. We find it very difficult to justify how often that we've spent, I don't know, £100k on a team of three people, handholding teachers. Most funders want to see participation rates jump, they don't want to see them crawl. And crawling is what you get if you're bringing hard-to-reach teachers into the fold.

Thus, in a context where resources are scarce, and where success is difficult to achieve, many providers may simply choose to work with those who are easier to reach. Moreover, the second comment points out how this is as much an issue for those who manage the community as those who work within it.

Given the evidence for the importance of learning experiences outside the classroom to educational attainment, three issues are of concern. First is the issue of whether enough is being done to provide for disadvantaged communities and their engagement with science. It is not that everybody needs to do everything, but there is a need for those who manage and support the system to ask this question and to ensure that such needs are met. Second, with the current policy concern about the future supply of STEM professionals,[66] it is surprising that not more concern was expressed about attracting and engaging more girls, women and other under-represented groups to science. Finally, there are few examples of good practice within the community and even less evidence that they are shared. As many of these under-represented communities are difficult and challenging to engage with, if the community is to become a learning community which builds its knowledge about how to work with under-represented groups, attempts need to be well-theorised, be designed in conjunction with the communities that they seek to engage, and share outcomes through easily available publications. From a systemic view, given the paucity of funds in the sector, it should be recognised that it is important that everyone in the community is provided for in some way – however, that does not require every provider to serve everyone. Ultimately, the responsibility for ensuring that the system addresses the needs of a diversity of audiences and operates in this manner is the responsibility of system managers.

66 Gove M. Speech to the Royal Society, London. June 29, 2011.

5. Supporting and managing the UK science education community as an ecological community: conclusion and recommendations

This work has been an attempt to apply an understanding of the properties of ecological communities to the question of supporting the creation of a robust and resilient UK science education community. The primary goal of this project was to begin this process of thinking of the science education system as a complex whole rather than as merely two semi-independent pieces comprising the pre-university formal education system and the informal education system – a binary division that serves neither. Our very preliminary scan of the UK science education system has only begun to scratch the surface of how to define and conceptualise it as a system. Nevertheless, a few key ideas do emerge. First and foremost is that the UK science education system is more complex and nuanced than the traditional formal–informal dichotomy suggests. Within the environment that this community exists in, there are many providers of educational experiences that address science. All of these contribute opportunities to learn or engage with elements of science. Hence, the artificial distinction between formal and informal learning is unhelpful. One consequence is that some in the informal sector undervalue what schools do and likewise too many in schools fail to recognise or exploit what is on offer to their students beyond the classroom walls. Moreover, for some, the terminology of 'formal' and 'informal' is not even widely recognised.

It is clear, then, that all those engaged in UK science education would benefit from perceiving themselves to be part of a community of providers of educational experiences that support science learning and engagement. To this end, all those who contribute to any form of science education, science communication or engagement in science need a set of goals around which help to define their purpose and cultural contribution to society. This might then help to weaken the divisionary and unhelpful practice of separating all education into formal or informal; learning is learning regardless of where it occurs.

In addition, there is a need for a more nuanced and synthetic discourse that promotes a vision of a complex community of providers of science education experiences, each of which contributes to the community's shared goals and occupies its own distinct niches.

In attempting to map the system of providers of science learning experiences, we have become aware of its diversity and complexity.

> **Recommendation 1**
> Our first recommendation, therefore, is that there is need to build a stronger sense of a common identity among all providers of science education or educational experiences that support science learning and engagement. To this end, all those who contribute to any form of education, communication or engagement in science need a set of goals to help define their purpose and cultural contribution to society – essentially a manifesto for STEM. The Wellcome Trust should therefore establish a group of stakeholders and providers of STEM education to develop a set of goals and aims for STEM providers. These should be published as a short pamphlet and in a variety of formats.

Our initial hypothesis was based on 18 sectors; the survey revealed 50 distinct entities, while our literature review suggested 31 entities. Although our work has provided some information, a better map would be provided by collecting data from within the system. Currently there is no central database which attempts to collect details of who is a provider, what kinds of experiences they offer, or how they see their work contributing to the wider community and its goals. It is impossible to argue for the importance of any particular sector or group of sectors and its contribution unless there is some sense of what it consists of, what the nature of its contributions is, and how it compliments other providers within the community.

> **Recommendation 2**
> Making the case for the value of the contribution made by informal providers of science education experiences requires better data on who works in the system, what are their goals and who they see as their audience. A central database needs to be established that registers such providers. The Wellcome Trust should establish such a database. Providers should be required to register their details as a condition of any funding and more broadly encouraged to do so by building a view that the data in this system are vital for defining the importance and contribution of the sector. As much of the data as possible on this database should be publicly accessible.

In defining the complexity of the science education community we return once again to our ecological analogy. Over the past decades ecologists have studied how the complicated structures and patterns of interaction within a community (such as our forest example) generate and sustain robust and resilient systems[67]. All ecological communities, including the UK science education community, are complex adaptive systems[68]. As ecologists have attempted to understand the nature of complex ecological communities, they have focused on a few key issues, in particular the relationship between the biodiversity and interactions within a community and the functioning of that system. Holland[67] identified four basic properties of healthy biological communities: diversity, aggregation, flows and nonlinearity. What are these concepts and what would they mean if what is true is for the ecological community of a forest is also true for the community that supports science education in the UK?

Concept 1: Diversity

The generation and maintenance of diversity is fundamental to healthy systems. The essential challenge, though, is to understand what sustains diversity at the level of a community and, ultimately, the overall ecosystem. It is often assumed that biodiversity simply represents the number of species present. However, as we saw in our analysis of the UK science education community, the key measure for understanding the complexity of a community is the diversity of niches that exist and their function, not the individual species

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67 Levins SA. Ecosystems and the biosphere as complex adaptive systems. Ecosystems,1998;1:431-6.
Mahonge C. Co-managing complex social-ecological systems in Tanzania. The case of Lake Jipe wetland. E-book. Wageningen, The Netherlands: Wageningen Academic Publishers; 2010.

68 Holland JE. Studying complex adapative systems. Journal of Systems Science & Complexity 2006;19(1):1-8.
Mason M. What is complexity theory and what are its implications for educational change? Educational Philosophy and Theory 2008;40(1):35-49.

themselves.[69] Thus, it is fair to say that UK science education has been enormously enriched by the expansion in the provision of learning opportunities. Nevertheless, our work has identified gaps. There is an abundance of effort focused on serving the school-aged population, but arguably insufficient priority given to adults and children under five, and little evidence of providers whose focus is on the T and M of STEM – particularly mathematics. Moreover, there is a lack of attention to the needs of underserved minorities.

Filling these gaps cannot be seen as the responsibility of any one niche or group of providers. It is simply too much to ask to suggest that individual providers be charged with remedying the flaws and weaknesses that exist within the whole ecological community. Although clearly many good things happen within the greater system in the absence of concerted community-wide management, in our view informed efforts directed towards system-wide management would yield better results than a *laissez-faire* approach. Our view is that this is best undertaken by a small board of senior people who either provide significant funds or have a vested interest in the system. Any assumption that it is solely a government responsibility is to ask too much of government, whose political responsibility is focused mainly on schools and only marginally on the provision of the myriad extra-curricular learning experiences that occur before, during, after and beyond schooling. Hence, it is highly recommended that key funding and policy stakeholders engage in managing the community *collaboratively*, which is an approach that has gained considerable traction in efforts to manage complex biological systems[70].

Recommendation 3

Hence, our third recommendation is that the Wellcome Trust should establish a small panel of major funders of out-of-school learning experiences whose responsibility would be to take a system overview. The aims and goals of this panel should be to:

a. commission reports and research on the functioning of different parts of the system

b. consider and review the strengths and weaknesses of the overall provision

c. take a strategic review, considering where the field needs to be strengthened, who or what is best capable of addressing that need, and how it could be funded

d. help define what are the priority aims and goals of the system as a whole.

While the focus of this panel will be on the informal sector, it would need to take a systemic view of the whole system that supports STEM learning. Hence, this panel should seek, as a priority, representation from the Department for Education and the Department for Business, Innovation and Skills so as to build a comprehensive system-wide view.

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69 Gell-Mann M. The Quark and the Jaguar: Adventures in the simple and the complex.San Francisco: WH Freeman; 1994.

70 Booker LS et al. Perspectives on Adapatation in Natural and Artificial Systems.Oxford: Oxford University Press; 2005.

Several points need to be made about this recommendation. The panel's sole function is strategic vision to discuss what is happening, whether the system has the appropriate endogenous and exogenous supports and whether it is meeting the needs of STEM learning for as many people as possible within funding and resource constraints. The panel should be small, consisting of a group of key funders, to maintain its effectiveness and value. Its goal is to build the system, taking a view about what is needed to build and sustain the system and to argue for the significance and value of all parts of the system within wider society. Second, the panel is not and cannot be a resource allocation committee, as each organisation is answerable to different policy makers, management committees and others. However, it would be a forum where information can be shared about what is or is not being offered. As such, it would help individual providers build a more systemic view, making it easier to avoid distortions in the system that threaten overall resilience and the capacity to adapt. Its primary goal would be to take a system overview, which no other body does, to explore the implications of current policy, and to act as an advocate for the value of the entire system.

Concept 2: Aggregation

This refers simply to the ways individuals are grouped into populations, populations into species, and species into functional groups. Any complex system develops what ecologists call 'inhomogeneities'[71,72]. In terms of the community that supports science learning, one such inhomogeneity is the fact that schools are so dominant while lacking engagement with others in the system – essentially the lack of reciprocation for the considerable attention they get from others in the system, as shown in figure 6. Whether schools can or should take on such a dominant role is questionable. For instance, a considerable body of evidence would suggest that school science has a negative effect on engagement for a substantial minority of students, particularly on young girls' engagement with the physical sciences[73]. Normally, the development of patterns of aggregation and hierarchical organisation is both a natural consequence of the self-organisation of any complex system and an essential element in the robustness and resilience of the community. However, because of their statutory nature, schools do not have to compete with other sectors for resources and thus have effectively distorted the community that supports the learning of science, and, for significant numbers of students, undermined the goal of ensuring that they all have a valued and engaging experience of science. The role of stimulating interest in science then falls disproportionately on other providers in the system.

If this analysis is correct, then it would suggest that the issue those who fund and support the system should be concerned about is ensuring a balance of experiences, both in and out of school, that ensures that lifelong interest and engagement with science, for building habits

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71 Law R et al. Ecological information from spatial patterns of plants: insights from point process theory. Journal of Ecology 2009;97:616-28.

72 Inhomogeneity refers to irregularity in a system – events not characterised by a fixed principle or rate, or that occur at irregular intervals.

73 Osborne JF et al. Attitudes towards science: a review of the literature and its Implications. International Journal of Science Education 2003;25(9):1049-79.

Bøe MV et al. Participation in science and technology: young people and achievement-related choices in late-modern societies. Studies in Science Education 2011;47(1):37-72.

of mind and long-term practices – particularly among young girls and under-represented minorities – is a system-wide outcome. This is, however, a non-trivial outcome to achieve and is unlikely to be accomplished by a single sector or by a limited set of experiences. Once again, this is where a more systemic, lifelong view of science education is required. As an application of community ecology concepts has demonstrated, understanding which of the functional groups within the system currently make important contributions to supporting the robustness and resilience of both child and adult engagement with science then becomes crucial.

Viewed in this manner, it is clear from our data that the field lacks robust measures of child or adult interest, has little understanding of how it can contribute to sustaining or developing an enduring interest or repertoires of practice, and does not know which of the sectors operating in the forest are critical or keystone groups and how their importance might vary with audience and goal. Developing such knowledge means that rather than asking what individuals have learned, the questions that should be asked are: how did a given experience contribute to stimulating or sustaining learner interest and engagement? In what way were participants challenged, surprised or helped to see something that they had never perceived before? How did this experience connect to other experiences and build long-term engagement with science learning? To answer these, it is first necessary to develop and refine the constructs of what we wish to measure, then develop reliable and valid measures and to build a deeper knowledge – all of which is a longer-term project. Achieving this goal is dependent on building expertise in research in evaluation within the system. It will not be served by asking evaluation to be undertaken by outside consultants – essentially itinerant foragers who specialise in finding any community where resources might exist, and who, once they have undertaken their work (eaten), depart to whichever next community affords them sufficient resources to work (feed) again.

Recommendation 4
The science learning and engagement system needs support to build its knowledge base of which outcomes to measure and the ways in which they might be measured. Currently, the work on evaluating the system and building knowledge is undertaken by a large diversity of people, far too many of whom inhabit other communities. The system therefore needs to establish one or more centres for research, evaluation and training, with a particular focus on non-classroom-based STEM learning, whose function would be:

a. to help build our knowledge of how to measure the outcomes of participants' experience

b. to conduct reviews of relevant research and produce summaries for the field

c. to foster collaboration between the institutions and providers that occupy different niches so that the system can support the building of interest and the engaged science learner

d. to develop a range of training programmes for new and established members of the community who work in non-school-based provision of science learning and engagement.

> To provide an incentive for providers to build and support the development of such centre(s), all bids for funding should be required to show how they have used, or intend to use, the expertise provided by these centre or alternatives.

Indeed, the fundamental reason for the New Forest being a National Park is the recognition that it will not survive as an ecological community unless it is managed to protect it from the long-term deleterious consequences of unsustainable activity.

These centres may be based across several sites and may consist of academics or practitioners working on fellowships. However, this would need, at a minimum, one person at each site who had a long-term commitment to its goals and their attainment, supplemented by additional staff if possible. Much of the income could be generated by commissioned work from the range of providers within the system. What is important is that these centres would be owned by and embedded within the system.

Concept 3: Flows

As already described, all ecological systems can be characterised by flows: flows of nutrients and energy, flows of materials, and flows of information. Such flows provide the interconnections between parts, and transform the community from a random collection of species into an integrated whole, a community in which all of the biotic parts are interrelated. Managing the flows within the system, both exogenous and endogenous, is fundamental to maintaining a balanced, healthy system. This is an additional point to support the case we make for recommendations 3. In addition, another 'nutrient' that feeds the system is the knowledge base on which it rests and the expertise of the people within it. As we have shown, although a knowledge base exists, it is neglected or ignored and thus remains functionally hidden and/or inaccessible.

In addition, there appear to be no formal mechanisms for anybody wishing to pursue a career within the community to gain recognised qualifications – a feature which is an essential criterion of a professional system. What the system needs is a repertoire of opportunities for professional training ranging from one-day courses for guides to one-year full-time courses at the Master's level for more senior staff. Again, this is a function that could be undertaken by the centres we propose. It would force members of the community to identify what knowledge is salient to sustain and build their work; it would contribute to building their own self-confidence and establishing external credibility. Locating this function within the centre structure would mean that it was owned by the community and answerable to them – a feature which we see to be important if its work is to be valued.

Concept 4: Nonlinearity

The property of nonlinearity is the change in the way the system interacts as the system evolves and develops. Complex adaptive systems change primarily through the reinforcement of chance events, such as mutation and environmental variation operating at local levels; the potential for alternative developmental pathways in a system is enormous. Given the structural constraints on the UK system that supports STEM learning, the possibility of such chance events is smaller and to some extent more manageable. Nevertheless, the considerable injection of funds via the Millennium funding programme has led to one such adaptation within the system. Whether all of the species that emerged as a consequence will survive is, of course, another question. The point we make here is that the decision to fund one element in the system is a decision not to fund other elements in the system and that all actions have unintended as well as intended consequences. Better decisions are likely to be made in the context of a system perspective – another point that we believe supports our first recommendation. Moreover, can the system be nudged with small incentives? While we would hesitate to spell out what these might be, one example would be to ask what can be done to encourage learners to use not only one institution but also to visit other institutions within the same or other sectors. For instance, many a science centre or museum at the moment seems to be more concerned about steering their visitors through the shop than planting the idea that there are other places to visit that might be equally engaging. Our point here is that institutions and providers need to do as much thinking about creating enduring engagement as they do about providing a one-off stimulating experience. The commercial world has managed to develop a range of models for building customer loyalty. And indeed, many institutions have developed forms of membership that facilitate repeat visits at little extra cost. However, developing an engaged and sustained interest in science needs to be the goal of the system as a whole. Providers need therefore not only to encourage young people to make repeated use of their own institution but also to make young people aware of other providers in the locality and what they offer, and provide incentives to make use of these too.

Recommendation 5

The community needs to build on the knowledge that it is generating from its experience – that is, it needs to become a learning community. In addition, it needs to develop and keep up to date with contemporary thinking about the nature of science, practices in formal science education, and ideas about learning, motivation and engagement in the educational literature. A number of mechanisms are suggested which would encourage the community to become a learning community. These are:

a. working with other funders to establish a concordat that requires all bids for funding to show where they build on the literature and what people may have done before

b. requiring all bids for funding to show how and what they would contribute to the existing knowledge base and how such knowledge would be shared, at least within their own niche if not more widely

c. producing short focused summaries of relevant research in PDF format, which could be sponsored by the Wellcome Trust, ensuring they have status and authority within the community (a good model is the summaries of findings produced by the OECD PISA programme)

d. exploring other ways to encourage practitioners to publish and to use the existing knowledge base

e. exploring ways of offering certification and professional development for individuals working in this field, such as by establishing a Wellcome Trust fellowship for the informal sector that is competitive and enables individuals to be released to undertake a programme of professional learning.

This analysis has begun to delve for the first time into defining the scope and scale of the heterogeneity within the UK science education community. Our efforts to begin to define the functional guilds within the community reveal a much more complex system than previously thought, though our understanding of the structure of the system remains at best preliminary. We have achieved only the most rudimentary understanding of the diversity, aggregation, flows and nonlinearity of the community, but we know that understanding, as well as managing, the system will require focusing on these aspects of the system.

Clearly, managing a complex system like the UK science education community will not be easy. We know that in heavily managed systems, simplified structures are too often imposed exogenously, rather than arising endogenously. As a consequence, they are unduly fragile and vulnerable to single stresses such as pest or disease outbreaks that cause system crashes in the absence of adaptive responses. Thus, if resilience is a goal, managers must understand the properties that enable communities to maintain their integrity in the face of changing environmental conditions and human intervention. Analogously, if we are to manage the UK science education system for both effectiveness and resilience, we need to determine how the combination of endogenous and exogenous factors can be designed to support diversification and improved reciprocal relationships between sectors, to identify and support keystone associations, and to identify the best use of financial support that rewards systemic approaches to shared goals. For example, the fact that our data show that currently there is an endogenous convergence within the community on what is considered important outcomes represents an opportunity for fostering systems thinking and collaboration through exogenous inputs (i.e. funding) about what it means to make something engaging – in short, to go beyond simplistic notions of 'fun'.

Finally, in order to manage the system thoughtfully and strategically, there is a need to conduct a more thorough and careful environmental resilience analysis of the UK science education community. Our work has simply been a start at characterising the system. Better decisions about the system, therefore, would be informed by a deeper understanding of answers to the following questions that could be further pursued by further research. These are:

a. What patterns exist in the distribution and organisation of diversity within the community?

b. Did these patterns organically form within local conditions or are they more historical?

c. What are the relationships between community structure and functioning?

d. What are the characteristics of key groups in this system, who are they and how can they best be supported?

e. Are there minimum thresholds of provision that can be optimised?

f. What factors seem to support or impede resilience within the community?

g. What roles do funders and other managers play?

h. What are the qualifications and experience of those who work in the system (the genetics of the species)?

The research conducted for this report has been the first that has attempted to examine the system that supports non-school-based STEM learning, and the Wellcome Trust should be commended for supporting this effort. As would be expected, our work raises many questions about the nature of the system to which we do not have good answers. We would hesitate to prioritise any one of the questions posed above; answering all of them will be necessary to informing those who support and feed the system. Collectively, such knowledge would provide a picture of the educational and professional expertise of both the pieces and the whole, and how it could be improved. A conference to discuss the findings and recommendations of this and the GHK report, and to explore their implications both for funding and further research, would be a first step in building the system and encouraging a more internal reflexive view of the system.

Methodological Annex: Data sources and methods used for the GHK report and the Stanford–Oregon State report

This Annex provides more detail about the data collection and analysis methods used for the literature review, interviews and surveys used in this report.

1. Data sources

This section describes the data sources that have been used for the Stanford–Oregon State report. Data were obtained from:

- a programme of in-depth qualitative interviews with stakeholders and broadcasters with an interest in informal science learning
- an internet-based survey of informal science learning providers
- literature and data review – the review of the 'grey literature' collected and the analysis of data from the Wellcome Trust Monitor and Public Attitudes to Science Survey
- responses from individuals to a survey administered at an invited symposium in May 2012.

More details of the data sources can be found in the methodological annex for the GHK report.

A. Stakeholder and broadcaster interviews

The questions used in the stakeholder interviews were developed jointly by the GHK and Stanford–Oregon State teams, and are provided in their methodological annex (See Appendix 1 in the methodological annex of the GHK report). Topics covered included:

- background on the organisation and its interest/involvement in informal science learning
- the other organisations it works with, and their respective roles
- the audiences it serves, and those it finds challenging to reach
- assessment policies and evaluation practices
- views on, and experience of, linking formal and informal science learning.

The stakeholder interviews also included an exercise to map out the relationships between organisations and to position the respondent on a grid comparing formality of venue and degree of free choice offered, for subsequent analysis by the Stanford/Oregon State team.

B. Survey of informal science learning providers

An internet-based survey was developed to collect the views of providers or supporters of informal science learning services. An online questionnaire was developed in collaboration with Stanford/Oregon State, a copy of which is provided in the GHK report in Appendix 2.

A sample of 366 organisations was developed for the survey from a variety of sources, including data from the STEM directories, the Wellcome Trust, ASDC and suggestions from the stakeholders interviewed. The survey was also promoted through psci-com, GEM, Visitors Studies Group and Big Chat distribution lists, to maximise coverage and allow as broad a range organisations to contribute as possible. No attempt was made to restrict responses to one per organisation, as the intention was to collect views from as broad a range of respondents as possible. It was also recognised that while the survey was never intending to be representative of the informal science learning sector as a whole, it aimed to feature a broad distribution of organisation types, sizes and activities.

The questionnaire required 20–30 minutes for completion, and included questions on:

- the respondent's organisation
- the activities delivered
- organisations collaborated with, and the nature of the any collaboration
- their audiences, any groups found challenging to engage and steps taken to engage them
- intended outcomes, evaluation practices and any challenges faced
- definitions of informal learning, and links between it and formal learning.

A total of 168 completed responses were received to the survey, with an additional 28 being sufficiently complete to allow their inclusion in the subsequent analysis. Details of the number of responses by organisation type are shown in table 3 in the Methods section of the GHK report. Of the 196 responses, 186 had sufficient data to be useful for Stanford/Oregon State purposes and were included in the analysis.

A second survey was created that was targeted specifically at schools and included a subset of questions from the original survey, modified specifically for educators in formal education. The target audience for this survey was coordinators of science programmes; participants were recruited primarily by emails sent to listservs for science programme coordinators in physics, biology, and chemistry. This survey was also administered online and received 23 complete responses.

The third survey used was a short version of the original online survey developed to target sectors for which there was a low response rate on the first survey (available from the authors on request). These questions were, again, taken from the original survey and administered online. Sectors that were targeted included libraries, community/hobby groups, broadcasters, parks and nature centres, publishers, science festivals, and theatre groups. Flyers with a link to the online survey were handed out to attendees at the final Wellcome Trust symposium in May 2012 and participants were asked to help recruit colleagues from these seven underrepresented sectors. In total, ten surveys were completed, all by broadcasters.

The final sample used by Stanford/Oregon State included 219 respondents.

C. *Responses to a survey conducted at an invited symposium at the Wellcome Trust in May 2012*

To test how familiar practitioners were with the most highly cited literature, and to determine what they considered to be their sources of professional information and knowledge, a survey was administered to all of the participants attending an invited Wellcome Trust-sponsored symposium on 28 May 2012. A copy of the survey instrument is provided in Appendix 2.

2. Review of existing literature – Stanford and Oregon State

2.1 Methods

The Stanford and Oregon State review of relevant literature was undertaken by the use of keywords in a systematic search using the academic journal databases ISI Web of Knowledge and CSA Illumina, cross-referenced against existing literature reviews and books about informal or free choice science learning. This search produced 561 unique articles. These were grouped by sector and analysed in more detail to explore the types of academic literature relevant to informal science learning. The data collection for the literature review for this study was conducted between October and December 2011.

To map the literature on informal science learning, four structured searches were conducted using the two academic journal databases. First, the terms used as search words were 'informal science learning' and 'free choice science learning' in the title, abstract and keywords fields. This search resulted in 755 unique references. Results were refined by year, removing papers prior to 1980 as this literature was older than 30 years and the field has developed substantially since then. In addition, only peer-reviewed articles (for CSA) and articles (for ISI) were included, to reduce literature such as conference proceedings and news bulletins, in order to distinguish academic from non-academic literature.

Second, to broaden the search, additional keywords considered relevant to informal science learning were used. Drawing on the terms defining the 18 sectors outlined in the proposal for this project and a keyword scoping exercise with existing literature reviews on informal science learning, these terms were used in conjunction with 'informal science' and 'free choice science' as a base for the next search, with the additional search words listed in Appendix 1.

The purpose of these searches was to identify literature related to informal science education that did not explicitly include the words 'informal science learning' or 'free choice science learning' in their titles, abstracts or keywords. 2346 articles were gathered using the above search terms in conjunction with the criteria that they be peer-reviewed articles and published post-1980. Merging the databases of the two searches produced a database with 2625 unique references, after removing duplicates.

Working with this database, irrelevant literature was then removed by asking the question: Is this literature related to informal science learning? In this process, a number of articles about medical research, arts-based research and library research were identified (using the additional search terms) but were not considered relevant to the research questions. Hence they were removed. At the end, there were a total of 358 entries.

The protocol for the manual removal of irrelevant literature was such that, for references with no abstracts (around 10–15 per cent of the whole database), the decision to include as relevant to informal science education or exclude as not was based on the title only. However, most references were screened by both title and abstract. Articles about technology, such as the use of the internet for science learning, were included in the filtering process because such technologies can often facilitate informal learning. Also excluded were a small number of articles not written in English.

A third round of searches was then conducted using 'science communication' and 'learning' as the base keywords, with the additional search terms 'young people', 'students' and 'children'. Using the previous searching method and criteria with ISI and CSA databases, this resulted in a total of 1827 results.

After manual removal of irrelevant literature, 179 entries from the new search were considered related to informal science learning. There were a large number of ICT-related papers, most of which were directly related to formal (rather than informal) education. Importing these new entries into the existing searches (i.e. with 358 entries) resulted in a database with 536 unique entries.

2.2. Cross-referencing and finalisation of literature review database

Even after these structured searches, certain relevant articles appeared to be missing. To ensure that the literature review included these articles, not to mention potentially missing articles, a fourth series of searches was carried out. The database developed thus far was cross-referenced with several existing sets of literature – e.g. Phipps's (2010) 'Research trends and findings from a decade (1997–2007) of research on informal science education and free-choice science learning'; Dierking and Falk's (1994) article 'Family behaviour and learning in informal science settings: a review of the research'; the NRC (2009) report *Learning Science in Informal Environments*; and Falk, Heimlich, and Foutz's (2009) book, *Free-Choice Learning and the Environment*. This resulted in an additional 372 new entries to the database, with 55 duplicate articles, which were removed. The outcome was an Endnote database of 864 entries.

As a result, the review undertaken was based on a database that is extensive and wide-ranging and that we believe captured most, if not all, of the relevant literature. The database was then filtered manually, assessing articles on the basis of whether they were relevant to contexts involving science, learning, communication and engagement in the UK. For the purposes of reliability, assessment of the salience of the literature was conducted by two researchers independently and then compared. Any disagreements were resolved through discussion. Articles retained in the database were a) about science and b) had clear relevance to informal science learning. The final number of entries in the database after this process was 553; these then imported into an NVivo database for analysis.

2.3 Analysis of literature review using NVivo

To analyse the 553 articles, the articles were coded by two researchers in two stages. First, each article was categorised according to which 'sectors of informal science learning' it belonged to – and this process was undertaken inductively (rather than assigned to the 18 sectors identified before the research began). Each article was also categorised for 'audience' (e.g. children, teacher, family), 'research methodology' (e.g. qualitative, quantitative, mixed), 'location' (e.g. UK, USA, international), 'research type' (e.g. empirical, review, theoretical), 'topic' (e.g. museum learning, school visit, technology learning) and 'other'. These categories were decided based upon reading the article abstract.

In the second phase, the codes for all 553 articles were revised into more appropriate groups. As a result articles were categorised into the following eight themes: 'year', 'sector', 'participants', 'location', 'literature type', 'research method', 'topic' and 'other'. Of these, the themes 'topic' and 'other' were assessed as too complex to analyse in detail across all 553 articles within the parameters of this project, thus only the remaining six themes were further refined at this stage. Using the 60 most cited articles, the content of these articles was analysed in more detail as described in the next section.

2.4 Review of the top 60 most cited articles

Citation counts obtained from Google Scholar were used as an indicator of how significant each paper has been in the field. This method of measurement offers an insight into the types of literature that are influential within the field

The initial review began with those articles which had 100 citations or more in Google Scholar – a total of 39 articles. To extend this further, the criterion for selection was then then set to 80 citations or more, which resulted in an additional 21 articles – 60 in total. This constituted 10 per cent of the literature in the database.

The coding of the 60 most cited articles followed a similar framework to the larger database (with 553 entries), albeit with more details. For example, coding included ‘purpose of study’, ‘literature type’, ‘theory’, ‘research methodology’, ‘participants’, ‘sample size’, ‘research method’, ‘data collection details’, ‘data analysis details’, and a broad category for ‘finding/nature of study’.

Each paper was initially coded with a theme that constituted the nature/key message of the article. These themes (i.e. lower-level concepts) were then grouped together by relevance and relatedness and later organised into a hierarchy which resulted in five key themes. Sections 3.1.1 to 3.1.5 in the report provides a brief description of the five major themes which emerged from the identification of related themes across the 60 most cited articles.

3. Analysis of interviews

51 of the 55 interviews conducted by the GHK team were analysed by the Stanford/Oregon State group. Those not analysed were the four interviews with academics and policy makers. The interviews were conducted by the GHK team using a mutually agreed upon interview schedule designed to explore the aims and values of each organisation, their main audiences, the activities they offered and how they perceived themselves within the larger science learning community (*see* Appendix 1 of the GHK Methods Annex for the full report).

All 51 interviews were transcribed verbatim and imported into NVivo for further analysis. An initial coding frame was constructed through open coding of the same interview by three researchers, looking for relevant and interesting themes. These preliminary themes were then discussed until a consensus was reached. Additional sub-themes were added under each main theme to include any data of interest that may not appear immediately relevant. A simplified version of the final coding scheme is given below, which includes the top-level themes but excludes the lower-level codes (including the many ‘other’ codes) as these are too numerous to list:

1. Organisation type
2. Aims and visions of organisation
3. Audiences
4. Activities on offer
5. Partners
6. Theory and values
7. Evaluation of activity
8. System (mapping exercise)
9. Definitions of informal learning
10. Points of note

Some of the above themes are not discussed in detail in the main report as either the theme is addressed in the GHK report, or it was not considered sufficiently relevant to the goals of the report, or there was insufficient data from the 51 interviews.

4. Analysis of survey data

In total, 219 survey responses were included in the analysis. Responses were coded and analysed using the SPSS software package as well as Microsoft Excel. Responses were organised by sector and examined for relationships with other sectors, perceived sector contributions, target audiences and reported outcomes. Network relationships were calculated using Excel and network maps were created using Gephi, an open-source graphing and analysis software (https://gephi.org). Other relationships were calculated by hand and plotted using Grapher (http://itools.subhashbose.com/grapher/), also an open-source graphing program.

Appendix 1: Keywords for systematic search of existing literature

Searches were initially conducted using the search terms 'informal' + 'science' + 'learning'. The search terms 'informal' + 'science' + [additional search words – see table below] were then used. These additional search words were generated from the sectors identified at the beginning of the study. Additionally, a separate set of search terms, 'science communication' + 'learning' + young people' or 'students' or 'children', was also used.

Table 1 Additional words used in searches

18 SECTORS	***Additional search words***	
Libraries	Library	
After school providers	After school activities	Saturday science clubs
	After school	Science clubs
Association for Science Education	Teacher training	Professional development
Commercial films, television, radio	Commercial media	Television
	Film	Radio
Educational films, television, radio	Educational films	Educational radio
	Educational television	Education media
Community groups	Hobby Clubs	Hobby
Electronic media producers	New Media	Social networking media
	Games	Phones
	Internet	Social networking
	Podcasts	
Parks/nature centres and field centres	Outdoor science learning	Outdoor
	National parks	Nature centres
	Environmental centres	Botanic gardens
	Field centres	
State/private schools	Formal education	Outreach
Publishers of books and magazines	Media	Newspapers
	Magazines	Books
School support groups	Young Engineers	Hands-on-Science
Science fairs/young scientist competitions	Young scientists competitions	Science festivals
Science learning centres	Science learning centres	
Science museums/centres	Informal learning institutions	Museum
	Science centres	Science discovery centres
Scientific societies/Science Council	Science council	Scientific societies
Sports clubs	Sports clubs	
Theatre groups	Science theatre	Science demonstrations
	Science circus	
Zoos/aquariums	Zoos	Aquaria/Aquarium
	Wild life centre	Wildlife park

Note: The term ‘science festival’ was also used without any base keywords due to absence of known literature.

Appendix 2: Survey for knowledge of literature

Name (optional)…………………………………………………………………………

What sector do you work in?..

i.e. Zoos, science centres, learned society, broadcast, new media, etc.

Please read through the list of references below. Please circle individually the names of any authors you recognise and please tick the box next to the reference if it is a book or paper you have read.

- ❑ Chawla, L. (1998). Significant Life Experiences Revisited: A Review of Research on Sources of Environmental Sensitivity. The Journal of Environmental Education, 29(3), 11-21.
- ❑ Costa, V. B. (1995). When science is another world – Relationships between worlds of family, friends, school and science. Science Education, 79(3), 313-333.
- ❑ DeWitt, J., & Storksdieck, M. (2008). A Short Review of School Field Trips: Key Findings from the Past and Implications for the Future. Visitor studies, 11(2), 181-197.
- ❑ Falk, J., & Dierking, L. D. (2000). *Learning from museums*. Walnut Creek, Lanham, New York and Oxford: AltaMira Press.
- ❑ Falk, J. H., Moussouri, T., & Coulson, D. (1998). The Effect of Visitors' Agendas on Museum Learning. *Curator: The Museum Journal, 41*(2), 107-120.
- ❑ Gammon, B. (1999). Everything We Currently Know about Making Visitor-Friendly Mechanical Interactive Exhibits. *Informal Learning*(39), 1,10-13.
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- ❑ Lucas, A. M. (1991). 'Info-Tainment' and Informal Sources for Learning Science. International Journal of Science Education. 13. 495-504.
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- Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A. S., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday sense-making. *Journal of Research in Science Teaching, 38*(5), 529-552.

Please add the names of any authors, books, journal articles or other references that inform your work….

Please read the list of publications below and tick the boxes to tell us whether you have a) ever heard of the publication/website or b) ever read anything in the publication/website.

Publication name	**Heard of?**	**Read?**
ASDC Newsletter or Website		
Computers & Education		
Curator		
Ecsite Newsletter or Website		
Environmental Education Research		
www.InformalScience.org		
International Journal of Science Education		
Journal of Research in Science Teaching		

Public Understanding of Science		
Research in Science Education		
Science Education		
Studies in Science Education		
Visitor Studies		

Please add the names of any other kinds of publications that inform your work…..

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Wellcome Trust
Gibbs Building
215 Euston Road
London NW1 2BE, UK
T +44 (0)20 7611 8888
F +44 (0)20 7611 8545
E contact@wellcome.ac.uk
www.wellcome.ac.uk

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